Combined Quantitative and Qualitative Analysis of the Thai Silk Industry

By

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Declaration

Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusions embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award.

Abstract

According to Thailand Textile Institute (2009), there was a consistent growth in silk based products over recent years. Silk represents a high value export from Thailand to international markets each year. The Ministry of Agriculture and Cooperatives (2010) however identified constraints that limit the expansion of Thailand's silk, and silk products. Although there are number of academics studying in order to solve those constraints, there is still no critical research project which truly studies in-depth regarding the current major problems and constraints in the Silk industry. The modern logistics and supply chain model is required for the expansion of the Thai silk industry (Thailand Textile Industry, 2009).

The goal of this thesis is to contribute towards developing a strategic supply chain and inventory model that support policy decisions of the Thai government and the key industrial decision makers. The research starts with the literature review of Thailand's textile industry and the major markets. The Thai silk industry's markets analysis, constraints, stakeholders, supply chains, and goals are then critically analysed. Case studies are developed based on eight representative Thai silk manufacturers in the experimental sections. Operational research (OR) models are used to measure efficiencies of the chosen Thai silk manufacturers' suppliers and inventory management processes. Data is collected pertinent to the Thai silk industry. In terms of data analysis, an algebraic model is formulated and the techniques of: the Analytical Hierarchy Process (AHP) for optimal decision making, Data Envelopment Analysis (DEA) for measuring efficiency, and Goal programming (GP) for optimising planning decisions in the presence of multiple conflicting objectives are used to suggest optimal solutions. Finally, the research contributions suggest improvements in the decision making process of suppliers and inventory management with respect to the case studies. This will link to the best practice framework that can be used to positively impact the Thai silk industry further, depending on the Thai government and key decision makers' requirements.

Acknowledgments

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Chapter 1 Introduction

1.1 Statement of Aim

Thailand's Deputy Prime Minister and Minister of Industry suggested that "there is more intense competition in the global market, there is a need for Thai textile and clothing entrepreneurs to adjust and make strategic changes as well as to develop new products and increase value added to be competitive in the market" (Thailand Textile Institute Book, cited by Watchravesringkan, 2009). Thus, it is important to understand how global competitors and trade liberalisation affect the future of these industries and what strategic adaptations they can use to reduce their constraints in order to respond to global competitiveness. When considering the most well-known type of textile and fabric in Thailand, Thai Silk is usually the first material considered. Silk fabric is one of the important products of Thailand from an international viewpoint. Furthermore, Thai silk is called "The Queen of Silk" (The Queen Sirikit Institute of Sericulture, 2009).

One key area that has received governmental support is that logistics and supply chain management. The Thai government has several ongoing projects designed to improve the efficiency of Thai exports and domestic products, including road expansion and improved transportation options (TTIS Textile Digest, 2008). The goal of this research is to contribute towards the development of supply chain and inventory management strategy for Thai silk that can support policy decisions of the Thai government and other key decision makers. The research will analyse the constraints that restrict the expansion of Thailand's silk industry. The research will then critically analyse existing supply chains of the Thai Silk Industry. The knowledge of supply chain and inventory management will be discussed. Operational research methods which are applicable to the thesis will be presented. Case studies will be developed for the thesis' primary research. There are eight representative Thai silk manufacturers involved. Operational research (OR) models will be used in this thesis to measure the efficiency of a set of major Thai silk manufacturers' existing suppliers and inventory management.

1.2 Research Objectives

This research is concerned with gaining a better understanding of the textile and clothing industry, with particular emphasis on Thai silk. The market conditions in textile and silk will be analysed. In order to achieve a competitive level of efficiency of Thailand's silk industry, a more in-depth study must be undertaken. In this thesis, a number of OR approaches are used to evaluate the efficiency in Thailand's silk industry regarding its supply chain and inventory structure, then to develop the supply chain and inventory management strategy that will benefit the Thai textile and silk industry. Operational Research (OR) techniques have given a vital contribution in textile and clothing areas, resource and distribution improving the cost-efficiency for the achievements. To achieve the research goals, objectives must be identified. The main objectives of this thesis are as follows:

1) To analyse the constraints that restrict the expansion of Thailand's silk industry in wider global trading networks.

2) To critically analyse existing supply chains of the Thai Silk Industry.

3) To critically apply operational research models to the case studies in order to identify the key decisions of the company owners and in order to measure the efficiency of the companies.

4) To develop optimal solutions for inventory management that supports policy decisions for key decision makers in the Thai silk industry.

After the main objectives identified at this point, there are a number of questions that are raised in order to support this thesis directions as follows:

(1) What are specific problems in Thailand's silk industry?

(2) Which of those problems will the research carry on for further study?

(3) In terms of reliability of the research, how will the Thai silk industry be impacted by the outcomes of this research?

(4) What kind of OR models can be used in order to solve the identified problems?

(5) What supply chains and inventory solutions can be proposed to key decision makers after elicitation of their professional preferences?

The research will then also lead to practical recommendations on how to improve decision making in the supply chain whenever these inventory management problems present themselves.

1.3 Research Methodology

The research involves an analysis of supply chain and inventory management of the Thai silk industry with the aim of suggesting means to improve its efficiency. Since supply chain and inventory management have become one of the critical important processes for doing business, it is very important to increase the efficiency of the supplier's performance and the flow of the production activities. The research project will start with a literature review in the area of the current supply chain conditions in Thailand. Data will be collected pertinent to the Thai silk industry. Case studies will be developed. These case studies will then be analysed from an operational research (OR) perspective. An Algebraic model will be formulated and the following techniques used: the Analytical Hierarchy Process (AHP) developed by Saaty (1970) will be used for effective preference elicitation from the companies, Data Envelopment Analysis (DEA) developed by Charnes et al. (1978) will be used for measuring the efficiency of suppliers and inventory management processes, and Goal programming (GP) developed by Charnes and Cooper (1961) will be used for optimising planning decisions in the presence of multiple conflicting objectives. The outcome will suggest improvements in the decision making process and configuration of the supply chain and manufacturers' inventory management. Conclusions will be drawn with respect to the case studies and to the supply chain and inventory management strategy of the Thai silk industry in general.

1.4 Resource needs and funding

The research has been funded by Rajamangala University of Technology Thanyaburi (RMUTT). The Primary data collection will be undertaken via the existing contacts within the Queen Sirikit Institute of Sericulture, The Federation of Thai Industries, the Thai Textile Clothing Membership Organisation, and The Queen Sirikit Department of Sericulture. These organisations agree to cooperate with this aspect of the research. Travelling to Thailand is needed for primary data collection. LINGO software was used to solve AHP DEA, and GP. Microsoft EXCEL was used for presenting graphical figures.

1.5 Thesis Outline

This research primarily analyse constraints that restrict the expansion of Thailand's silk industry. Then operational research models are critically applied to the case studies in order to support real decisions of company owners and in order to measure efficiency of the companies with respect to their supply chain and inventory management processes. This thesis is structured into eight chapters, as follows:

Chapter 1: introduces the subject area of the research, including a basic background, motivation, objectives, scope, research questions, and the structure of the research.

Chapter 2: will be a discussion regarding the literature of Thailand Textile Industry Overview, Statistic Information of Thailand Textile Industry, Overview Supply Chains and Stakeholders of the Thai Silk Industry, Key Issues within the Thai Silk Factories, Supply chains and inventory management, and Operational Research Models.

Chapter 3: introduces the methods used for data collection and analysis. This chapter also discusses research design, and its structure. Finally, the conclusion of the expected outcomes will be explained before commencing the experimental chapters.

Chapter 4: aims to understand how key decision makers from case studies set importance weights based on the specific criteria provided. The chapter includes two main sections for each individual case study. The first section will detail the application of the analytical hierarchy process (AHP) to a supplier selection problem. The second section applies AHP to the inventory management processes of each company. It then concludes with a brief summary of the analysis of this research.

Chapter 5: presents the method that can be used to solve inconsistencies in pairwise comparisons. The method was introduced by Gonzalez and Romero (2003). The paper proposed Goal Programming (GP) as an attractive and flexible tool for a distance-based framework for analysing this kind of compatibility. According to data analysis, computer software LINGO and Microsoft Excel was applied as analytical tools. GP achievement function was translated into LINGO version 14 format. The Microsoft Excel was used for stocking all data and presenting all graphical data.

Chapter 6: presents the method of using Data Envelopment Analysis (DEA), which is used for measuring an efficiency of the case study companies' existing suppliers and inventory departments. Concepts of the Thai silk manufacturers efficiency analysis will be introduced. The means of model analysis will be also discussed, and the sets of inputs and outputs used are detailed.

Chapter 7: specifically focuses on an analysis of inventory optimisation. Several Goal Programming models will be built in order to obtain an optimal sets of actions, representing different manufacturers' preferences. There are three specific GP models used for analysis in this chapter as follows; Weighted, Extended, and Chebyshev. In terms of the optimisation, the goals used in GP models use preferential weights derived from the AHP analysis (Chapters 5). Finally, an optimal solution for inventory management that supports policy decisions of key decision makers will be obtained.

Chapter 8: concludes by discussing key findings derived from the research questions, major contributions, and limitations of this research. At the beginning of this chapter, the key findings of this research obtained from the analysis of the results are discussed in detail based on the research questions that are described in Chapter 1. The research contributions are then discussed. Finally, areas of further research are given.

Chapter 2 Literature review

2.1 Introduction

This chapter provides a relative philosophy of Thailand’s textile industry, the industry’s statistic information, supply chains, stakeholders, key issues, operational research models Supply chain and inventory management. Finally, the summary will then draw out a description of gaps in the current research literature.

2.2 Thailand Textile Industry Overview

The Thai government has established a consortium for SMEs (Small and medium-sized enterprises), supported by the Department of Export Promotion to develop the internationalisation potential of Thailand's 80,000 small and medium sized enterprises in the Thai textile industry (Johnsen, 2007). The Thailand Textile Institute (2009) reported a consistent growth in silk and silk based products. Silk represents a high value export from Thailand to international markets each year. However, the Ministry of Agriculture and Cooperatives (2010) has identified constraints that limit the expansion of Thailand’s silk, and silk products, in international markets and trading networks. Thai silk production and processing are highly labour intensive activities and are suffering from competition from countries with lower costs such as China, and India. These countries in recent years have invested in manufacturing methods, management and marketing systems (The Queen Sirikit institute of sericulture, 2009) which have increased the competitive pressures on Thailand’s industry. Namchaisiri (2007) identifies the major problems that hinder the forward integration of the industry; Quick Response/Supply Chain, Product Distinctiveness/Variety, and Technology/Machinery. The Kasikorn research centre (2006) (formally the Thai Farmers Research Centre) suggests there is potential for Thai silk exports to increase in the future despite competition from other Asian competitors.

In addition to offering more opportunities following the expansion of markets to the ASEAN (The Association of Southeast Asian Nations), globalisation and textile and apparel trade liberalisation have posed many challenges to Thailand's textile and clothing industry. Additionally, there is growing intensive competitiveness from China and other Asian countries (e.g. India, Vietnam) (Watchravesringkan, 2009). Moreover, according to Appelbaum and Curran (cited by Watchravesringkan, 2009) the elimination of the Multi-Fiber Agreement in 2005 was the result in changing the competitiveness for many national industries. These concerns have been raised regarding how on-going trade liberalisation has been created. In order to gain a better understanding of the overall Textile industry in Thailand, the next section (2.3) will represent statistical information as: the major markets, in-depth statistical data for Thailand's textile exports and imports classified by the major markets, and (2.4) will conclude overall markets analysis of Thailand textile industry and will then discuss silk markets .

2.3 Statistical analysis of Thailand Textile Industry.

2.3.1 The Major Markets of the Thailand Textile Industry

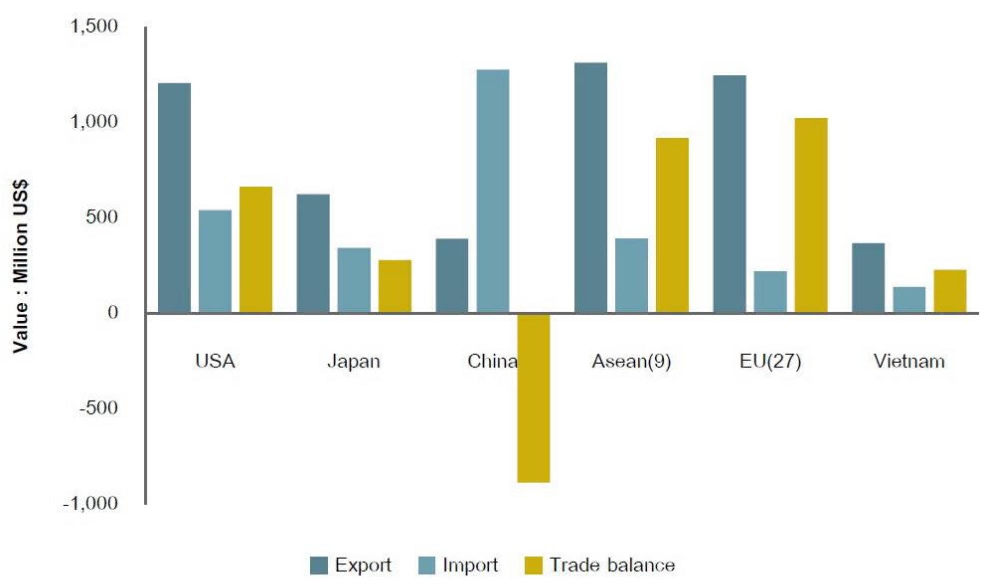

Figure 2.1: The Major Markets of the Thailand Textile Industry
Source: Thailand Textile Institute, (2011).

Figure 2.1 represents the directions of trading balance of the major markets of Thailand home textile and apparel products. Thailand had done well regarding the trade balance with the major markets, except from China where 888.5 Million US dollars is the loss of the trading balances. Most of this is from fabric categories including silk. The biggest export market was the ASEAN which is around 1200 million US dollars. USA and EU were almost the same in terms of exports rate. In 2011, ASEAN countries became the top exports market following by EU, USA, Others, Japan, and China. In terms of fabric markets, the biggest exports market was ASEAN countries in 2008-2011. By consider the growth rate in 2011, the most active market was Japan (141.4% increasing). China also had an improved growth rate at 19.2% for Thailand's fabric exports (Textile Digest, 2012).

2.3.2 China Market

China	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	253.4	268.7	390.6	304.8	391.3	28.4
Import	1,072.4	898.1	1,319.0	1,048.7	1,276.8	21.8

**value=Million US$

Table 2.1: Thailand Textile's (Export) and (Import) Value to China
Source: Thailand Textile Institute, 2011

Table 2.1 represent represents the values of exports and imports that Thailand has been trading with “China”. The information show that the increasing of exports are higher than imports. However, the ratios between exports and imports are very high, which means Thailand has been losing a balance of trade to China. In terms of exports, yarn is the most active product to China. In terms of imports, fabric is the most active product (Textile Digest, 2012).

2.3.3 ASEAN Market

ASEAN	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	1,024.0	1,014.6	1,364.8	1,099.2	1,311.9	19.4
Import	334.2	269.3	387.6	316.2	393.9	24.4

**value=Million US$

Table 2.2: Thailand Textile's (Export) and (Import) Value to ASEAN

Source: Thailand Textile Institute, 2011

Table 2.2 represent the values of exports and imports that Thailand has been trading with "ASEAN countries". The information shows that the increasing of imports are higher than exports. However, the ratios between exports and imports are very high, which means Thailand has been gaining a high balance of trade from ASEAN. In terms of exports, fabric is the most active product to ASEAN. In terms of imports, yarn is the most active product (Textile Digest, 2012).

2.3.4 EU Market

EU(27)	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	1,421.6	1,262.4	1,413.5	1,154.7	1,245.9	7.9
Import	308.1	206.8	240.8	196.9	222.2	12.8

**value=Million US$

Table 2.3: Thailand Textile's (Export) and (Import)Value to EU

Source: Thailand Textile Institute, 2011

Table 2.3 represents the values of exports and imports that Thailand has been trading with "European countries". The information shows that the increasing of imports are higher than exports. However, the ratios between exports and imports are very high, which means Thailand has been gaining a high balance of trade from European countries. In terms of exports, apparel is the most active product to the EU. In terms of imports, fabric is the most active product (Textile Digest, 2012).

2.3.5 Japan Market

Japan	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	470.4	450.8	534.8	431.8	624.8	44.7
Import	337.9	242.2	345.36	282.7	343.9	21.6

**value=Million US$

Table 2.4: Thailand Textile's (Export) and (Import) Value to Japan
Source: Thailand Textile Institute, 2011

Table 2.4 represents the values of exports and imports that Thailand has been trading with "Japan". The information show that the increasing of exports are higher than imports. Considering to the ratios between exports and imports, Thailand has been gaining a good balance of trade from Japan. In terms of exports, fabric is the most active product to Japan. In terms of imports, fabric is the most active product (Textile Digest, 2012).

2.3.6 USA Market

USA	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	1,932.2	1,421.3	1,524.1	1,275.1	1,206.1	-5.4
Import	424.4	260.7	321.9	272.6	542.1	98.9

**value=Million US$

Table 2.5: Thailand Textile's (Export) and (Import) Value to USA
Source: Thailand Textile Institute, 2011

Table 2.5 represents the values of exports and imports that Thailand has been trading with "the USA". The information shows that the increasing of imports are higher than exports. However, the ratios between exports and imports are very high, which means Thailand has been gaining a high balance of trade from the USA. In terms of exports, apparel is the most active product to USA. In terms of imports, fibre is the most active product (Textile Digest, 2012).

2.3.7 Vietnam Market

Vietnam	2008	2009	2010	2010 (Jan-Sep)	2011 (Jan-Sep)	±in%
Export	224.6	250.4	333.6	266.2	368.4	38.4
Import	86.2	78.5	125.3	101.0	139.8	38.4

**value=Million US$

Table 2.6: Thailand Textile's (Export) and (Import) Value to Vietnam

Source: Thailand Textile Institute, 2011

Table 2.6 represents the values of exports and imports that Thailand has been trading with "Vietnam". The information shows that the increasing of imports are equal to exports. However, there has been a difference between exports and imports, which represent that Thailand has been gaining a good balance of trade from Vietnam. In terms of exports, fabric is the most active product to Vietnam. In terms of imports, yarn is the most active product (Textile Digest, 2012).

2.4 Markets Analysis

According to a recent Thailand Textile Institute (2011), overall textile and apparel exports has increased slightly over a year (2005-2011). Likewise, in each category of woven fabrics, which includes cotton, man-made fiber, silk or silk waste, and other textile material, there was positive growth. The sub-categories that showed consistent growth were silk or silk waste garments, brassieres, and gloves. Other garments such as cotton, man-made fiber, wool or fine animal hair, and baby garments fluctuated in export levels or consistently declined. The US market has been the top importer of Thai textile and apparel products, followed by the EU, ASEAN, and Japanese markets. The imports of fabrics particularly silk and wool/animal hair products, have consistently increased.

In terms of silk industry, silk represents a tiny percentage of the global textile fiber market. Globally, cotton accounts for 40% of the world fiber consumption, wool accounts for a mere 2.5%, and silk accounts for a tiny 0.2% (WTO, 2008). Yet, the actual trading value of silk and silk products is much more significant than this volume would suggest.

Silk is a premium priced agricultural commodity; the unit price of raw silk is roughly twenty times that of raw cotton (FAOSTAT, 2007).

Thailand is the sixth largest raw silk producer with about 1% of the world production and is ranked seventh in term of raw silk imports (about 3% of the world imports). Thailand, being one of the world's leading textile producers, is dependent on imported raw silk to meet the demands from the textile industry due to limited domestic supplies (Watchravesringkan, 2009). It appears difficult to predict global consumption trends of silk. This is because silk products tend to share the characteristics of luxury products, which are not very sensitive to price changes. In the long run, demand is affected by factors such as fashion trends, promotion, and changing attitudes of the public toward natural fibers and textile products. Promotion of silk and natural fiber can have a major effect on demand and attitudes of consumers. The next section (2.5) discusses the Thai silk industry.

2.5 The Thai Silk Industry

Thailand has a millennia-old tradition of silk production that has survived up to the present day because of the country's relatively stable economic environment (Graham, 2011). Although silk weaving in Thailand is an ancient practice, many people mark the arrival of a foreigner, Jim Thompson, as a turning point in the Thai silk industry. Fifty years ago, Thompson started a company that focused almost exclusively on exports, and his company is now the largest silk company in Thailand (Graham, 2008). Thompson redesigned looms, imported higher quality raw silk, and encouraged producers to weave new patterns that would be appealing to foreigners. The company controlled, and still controls, all of the nodes of production on its supply chains. However, over the past few decades hundreds of former employees have started their own silk businesses focused on international trade (Haggblade, 2006). Today, Thailand's silk industry lags significantly behind China's and India's in terms of total raw and finished silk production (UNCTAD/WTO 1997, 2002)

Figure 2.2: Thai Silk Fabric

Source: Thai Silk Fabrics, 2012

Figure 2.2 represents a variety of traditional Thai silk fabrics that have been produced in the industry. Thai silk is produced from the cocoons of Thai silkworms. Thai weavers, mainly from the northeast region of Thailand, raise the caterpillars on a steady diet of mulberry leaves. The northeast region is the centre of the silk industry in Thailand and a steady supplier of Thai silk for many generations (The Thai Silk Fabrics, 2012). Today, Thai silk is famous for its special qualities produced through unparalleled manufacturing processes, bearing unique patterns and colours.

2.6 Stakeholders of the Thai Silk Industry

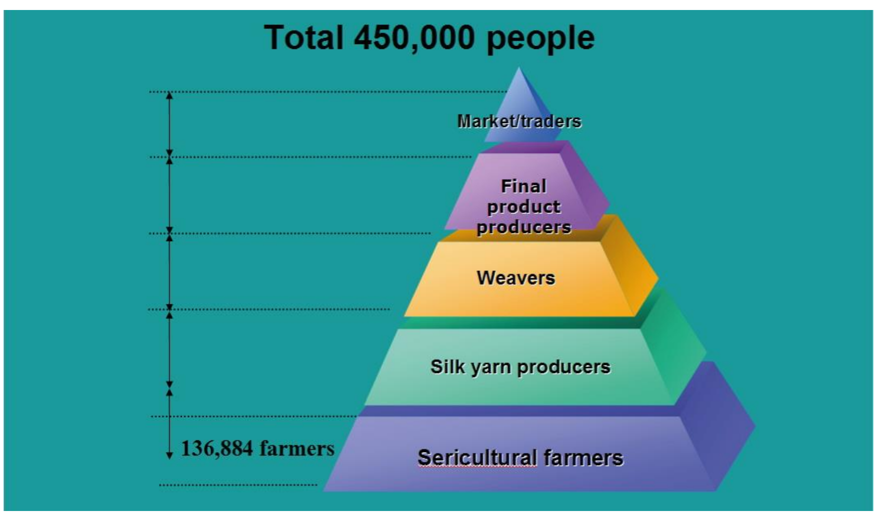

Figure 2.3: Stakeholder of the Thai Silk Industry.

Source: The Queen Sirikit Institute of Sericulture, 2011

Figure 2.3 represents the overall stakeholder breakdown in the industry which consists of farmers, silk yarn producers, weavers, final product producers, and marketers. The total number of people involved is about 450,000 within the Thai silk industry itself. The largest section is farmers which is around 136,884. Siewsamdangdet, et al (2010) states that Thailand's silk industry in the northeast area can be classified into three sections as, Upstream supply chain (Sericultural farmers), Process supply chain (silk yarn producers weavers, and final product producers), and Downstream supply chain (marketers/ traders). The in-depth review of the supply chains will be detailed in the next section:

2.6.1 In-depth Supply Chains Structure of the Thai Silk Industry.

The Northeastern home textiles sector is not at all well integrated and the silk sector is relatively complex. Some farmers raise silkworms and sell cocoons for processing in factories; some raise silkworms, reel the cocoons and sell silk yarn, either to other villagers or to weaving factories; some villagers buy yarn and concentrate on dyeing and weaving; and some complete the whole process from planting and maintaining their mulberry plots for silkworm rearing up to selling dyed woven fabrics and products (EU-Thailand Small Projects Facility, 2007).

2.6.1.1 Silkworm Egg Suppliers

The silkworm variety is the primary determinant of the characteristics of the entire silk value chain. Currently the silk production in Thailand is almost 100% mulberry silk from three major Mulberry silkworm varieties; polyvoltine (Native Mulberry silkworm), poly-bivoltine (Thai Mulberry silkworm), and bivoltine (Foreign Mulberry silkworm hybrids) (EU-Thailand Small Projects Facility, 2007).

2.6.1.2 Rearers

Rearers are engaged in hatching silkworm eggs and rearing silkworms until they spin their cocoons. They are responsible for retaining the quality of cocoons by giving proper nutrition and care in the early silkworm stages. Most rearers also have their own small mulberry plantations to grow fodder for their silkworms. Rearers link to silkworm egg suppliers for obtaining silkworm eggs and they also link to reelers by supplying them with cocoons for further reeling processes (EU-Thailand Small Projects Facility, 2007).

2.6.1.3 Reelers

Reelers buy cocoons from rearers and reel raw silk from these cocoons. The quantity and the quality of raw silk largely depend on the amount and the quality of cocoons and the used reeling technology. There are two types of yarn produced in Thailand; hand reeled and machine reeled. These two technologies correspond with the variety of cocoons to be reeled. Polyvoltine varieties can only be hand reeled as the filament is not strong enough to be reeled by powered reeling machines. Factory reeling with large motor powered machines is almost exclusively done with bivoltine cocoons purchased from contract farmers. This reeling takes place on a commercial scale, producing both weft as well as warp yarn. Most of the yarn produced in Thailand is weft yarn as it is hand reeled yarn with variable thickness. As a consequence, warp yarn needs to be imported, mainly from China and Vietnam (EU-Thailand Small Projects Facility, 2007).

2.6.1.4 Yarn & Fabric Traders

There are more than 200 traders in the Northeast getting silk yarn supplies from polyvoltine and poly-bivoltine reelers and bivoltine reeling factories. Yarn traders at the village level sell mainly polyvoltine yarn. They sell to individual households and dyers inside their village or in nearby villages as well as that they trade with community, district and provincial level weaving factories. District and provincial level traders normally sell yarn under contract (both formal and semi-formal) to weaving factories within their province or from different provinces. More than 200 traders in the Northeast obtain silk fabrics from weavers. These silk fabrics are further supplied to home textile producers (EU-Thailand Small Projects Facility, 2007).

2.6.1.5 Dyers

There are more than 200 dyers in the Northeast who are responsible for dyeing the yarn. Silk colouring involves operations such as de-gumming, bleaching and dyeing. Non-processed yarns are derived from three sources: hand reelers, reeling factories (machine reelers) and yarn traders. Natural dyes generally come from fruits, leaves, roots, etc.

which are available locally. Chemical dyes are also applied in the dyeing process due to the scarcity of natural dyes and their drawbacks in terms of colour fading, limited colour palette, etc. Chemical dyes can be obtained from yarn traders or local input suppliers. After the process of yarn dyeing is completed, dyed yarns will be distributed to weavers to be used in the weaving process (EU-Thailand Small Projects Facility, 2007).

2.6.1.6 Weavers

Silk weaving is done on handlooms as well as power looms. There are 5 different types of weavers involved in the weaving process in the Northeast; handloom weavers, power loom weavers, handloom weavers with yarn dyeing facilities, handloom weavers with yarn dyeing and printing facilities and power loom weavers with yarn dyeing and printing facilities. The first two types obtain dyed yarns from dyers while the last three types receive non-processed yarns from traders or directly from reeling factories (EU-Thailand Small Projects Facility, 2007).

2.6.1.7 Printers

Printing is a method of colouring fabrics. Small-scale weavers generally do not have a printing capability because of the high investment costs. If fabrics need to be printed they will be sent to printing factories. There are more than 30 fabric-printing factories in the Northeast. They charge for printing according to pattern and number of yards. Printed silk fabrics will then be distributed to home textile producers for sewing and finishing (EU-Thailand Small Projects Facility, 2007).

2.6.1.8 Home Textile Producers

There are more than 300 home textile producers in the northeast who undertake sewing and finishing in two different ways. One type of home textile producer controls most of the supply processes starting with silkworm raising, yarn making, yarn dyeing, hand weaving, until the final production of home textile products such as scarves, placemats, bed covers, pillow cases, etc. The specific designs and colours, as well as weaving techniques reflect the cultures of different rural communities (EU-Thailand Small Projects Facility, 2007).

The second type of producer is producing home textiles from materials acquired in the market. These materials include fabrics from handloom weavers, fabrics from weaving factories and fabrics from fabric traders. As stated previously, home textile producers require proper professional design input to cope with changing fashion trends. In order to be able to adapt quickly to changing demand, a continuous development of designs is required. Figure 2.4 represents the overall steps from Mulberry tree to finished products (EU-Thailand Small Projects Facility, 2007).

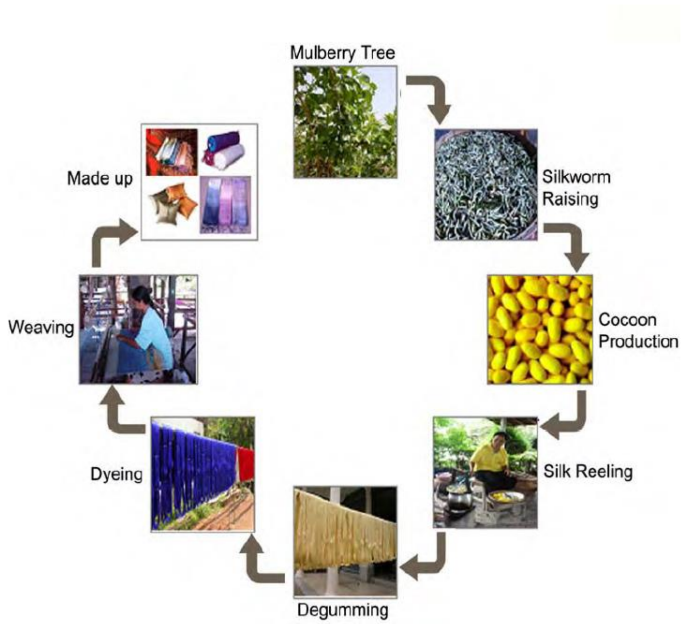

Figure 2.4: The process steps from silkworm rearing to home textile products
Source: Thai Silk Fabrics, 2012

2.6.1.9 Trading Agencies/ Exporters

Trading agencies/ exporters source home textile products directly from local home textile producers and supply these products to international buyers in different countries such as the US, Japan, the EU, etc. There are more than 200 trading agencies/exporters in Thailand but only one large exporter (Jim Thompson, officially known as The Thai Silk Co., Ltd.) is dominating the market with a market share of over 50%. Jim Thompson is a successful case of vertical integration in silk production. The company is supplying silkworm eggs, producing its own yarn, purchasing yarn from smallholders for processing, weaving, designing and printing its fabrics, tailoring these fabrics in its factories and is marketing its products through retail shops named Jim Thompson in many countries around the world (EU-Thailand Small Projects Facility, 2007).

2.6.1.10 Traders/ Domestic Wholesalers

There are more than 300 traders/domestic wholesalers who service local retail outlets as well as traders/domestic wholesalers in other regions. These markets receive fair to good quality products from home textile producers with prices that are similar to those offered to trading agencies/exporters. Traders/domestic wholesalers link producers to local retail outlets, provide market access for producers, supply finished products to domestic chain retail outlets and act as an information broker between the two. The relationship between producer, trader and retailer is normally long-term and informal, often with no written contracts. Business dealings are done based on trust. Traders/domestic wholesalers buy home textile products from their producers and pack these products according to orders from local retailers (EU-Thailand Small Projects Facility, 2007).

2.6.1.11 Local Retail Outlets

There are several local retail outlets such as street vendors and formal retail traders who receive home textile products directly from home textile producers or from traders/domestic wholesalers. Tourists and local people are the main customers for street vendors. For the formal retail traders, there are several fairs and exhibitions, organised by the government, both at provincial as well as national level. National trade fairs which are very well known include the OTOP and the Made in Thailand Trade Fair. The Department of Export Promotion and the Community Development Department are organising the OTOP fairs 2 to 3 times per year. Provincial trade fairs include annual fairs organized at each province (EU-Thailand Small Projects Facility, 2007).

2.7 Thai Silk's Qualities Classification

Thai silk is mostly home products with different production techniques which result in different qualities of silk. The quality of Thai silk had not officially been certified and the different types of silk have not been categorised. Many silk buyers were disappointed to find that the quality of Thai silk they bought was not up to their expectations (Ministry of

Agriculture and Cooperatives, 2010). The Ministry of Agriculture, therefore, announced that from now on a peacock emblem bestowed by Her Majesty the Queen will be used to guarantee the quality of Thai silk.

To be able to identify genuine Thai silk easily, Thailand's Agriculture Ministry uses a peacock emblem to authenticate Thai silk and protect it from imitations. The peacock emblem serves as a guarantee of quality and it comes in four different colours based on specific silk types and production processes. These are the following:

Figure 2.5: Thai Silk Classification Logos
Source: The Royal Peacock Logo, 2014

Gold Silk products are made from native silk worms in both the warp and the weft. They may be decorated with not more than 20% of silver or gold threads. Weaving process: The silk must be hand-spun using simple folk tools. The thread has to be graded after its reeling process, and woven with a wooden hand-loom (The Royal Peacock Logo, 2014).

Silver Silk products are made from native silk worms or hybrids (imported silk worms developed in Thailand) in either the warp or the weft thread. They may be decorated with not more than 20% of silver or gold threads. Weaving process: The silk must be hand-spun and woven with a wooden hand-loom (The Royal Peacock Logo, 2014).

Blue Silk products are made from native or modified silk worms for both the warp and the weft thread. Those using foreign silk threads must be clearly indicated on the products. They may be decorated with not more than 20% of silver or gold threads. Weaving process: No restrictions on the reeling and weaving processes (The Royal Peacock Logo, 2014).

Green Silk products are made from native silk worms as a main source of materials with other fabrics as complimentary components. The proportion must be clearly indicated on the products. Other decorative materials can be used. Weaving process: No restrictions on the reeling and weaving processes (The Royal Peacock Logo, 2014).

In conclusion, Thai silk can be made to meet any of the four Royal Peacock standards. Quite independently, the silk can also be certified to meet the particular standard it is made to meet. A Thai government silk inspector inspects the actual fabric being certified. If the fabric meets the standard, individually numbered seals with the Royal Peacock logo are placed at every meter along the length of the fabric as proof of certification (The Royal Peacock Logo, 2014). In order to understand the overall production processes and supply chains of the industry, the next sections will discuss production activities of the Thai Silk, and key issues found in the Thai Silk Factories.

2.8 Thai Silk Production Activities

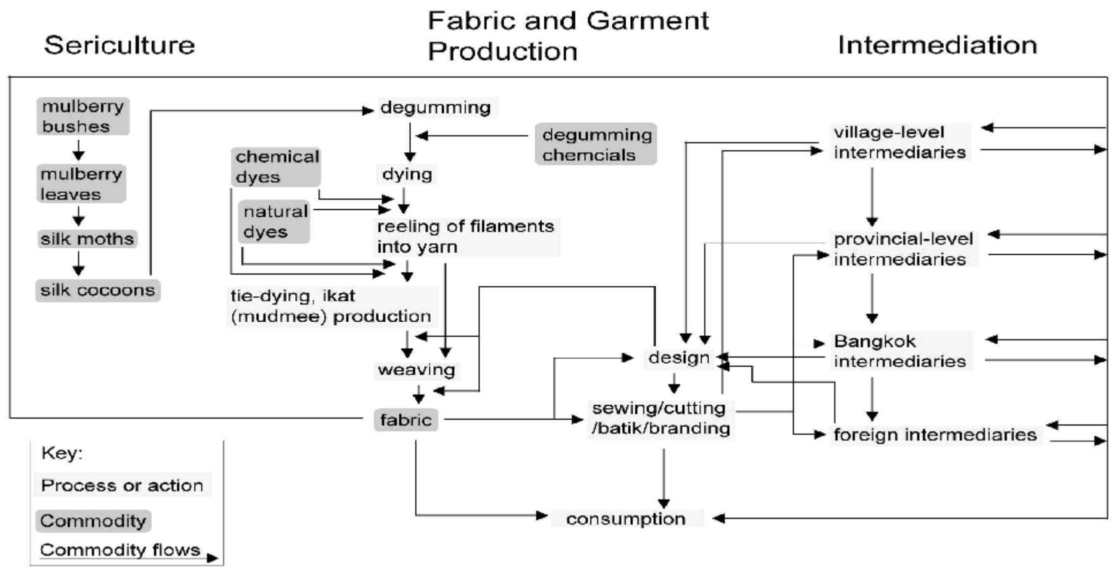

Figure 2.6: Commodity Chains of Thai Silk

Source: Graham, 2008

Figure 2.6 represents the overall production activities of Thai silk. The first process is Sericulture, which is considered to be the foundation and also called the upstream supply-chain. The following process is fabric and garment production, also called the middle stream supply chain. The last process is intermediation where marketing and purchasing activities taken parts, also called the downstream Supply-chain. In order to understand overall production processes of Thai silk production, the next section will be presented regarding the case study done by the particular group of logistic researchers (Thailand Textiles Supply Chain Development Handbook, 2008).

2.9 Key Issues within Thai Silk Factories.

To identify what are the major problems discovered in many clothing and textile factories, this section provides the interesting case being studied by the group of professional researchers. According to Komolavanij et al. (2008), the researchers analysed production processes of the product in Thai silk manufacturer (Classic Model LTD.) The selected product was the Thai silk Jeans. The researchers used analysis techniques as follows: Value Stream Analysis, Swim lane Diagram, and Activity-Based Costing (ABC). The following tables represent the collected data from in-depth study in the factory.

No	Events	Event Symbol					Time	Distance	Activities		
		operation	Transprotation	Storage	Delay	Inspection	Hours/Days	Metre/Km.			
1	Design	●	⇨	▽	D	□	2 Days		x		
2	Calculate fabric for productions	●	⇨	▽	D	□	2 Hours		x		
3	Patern Making	●	⇨	▽	D	□	1 Day		x		
4	Transport to Dyeing	○	➡	▽	D	□	1 Hour			x	
5	Dyeing process	●	⇨	▽	D	□	1 Day		x		
6	Transport back to the warehouse (the Classic)	○	➡	▽	D	□	1 Hour			x	
7	Lining Technique on the fabric	●	⇨	▽	D	□	1 Day		x		
8	Cuttings	●	⇨	▽	D	□	4 Hours		x		
9	Sewing	●	⇨	▽	D	□	2 Days		x		
10	Transport to Detailing	○	➡	▽	D	□		2 Metre		x	
11	Detailing process	●	⇨	▽	D	□	1 Day		x		
12	Transport to Inspection	○	➡	▽	D	□		2 Metre		x	
13	Inspection process	○	⇨	▽	D	■	1 Day				x
14		○	⇨	▽	D	□					

Table 2.7: The Presentation of Value Stream Analysis of the Thai Silk Jeans
Source: Komolavanij et al, 2008

Table 2.7 represents how Value stream analysis was used to divide production processes into each individual sub events such as operations, transportations, storages, delays, inspections, times and distances. This table also helped producers and researchers to know overall processes of one single product. Design and Sewing took 2 days for each which has the longest lead time.

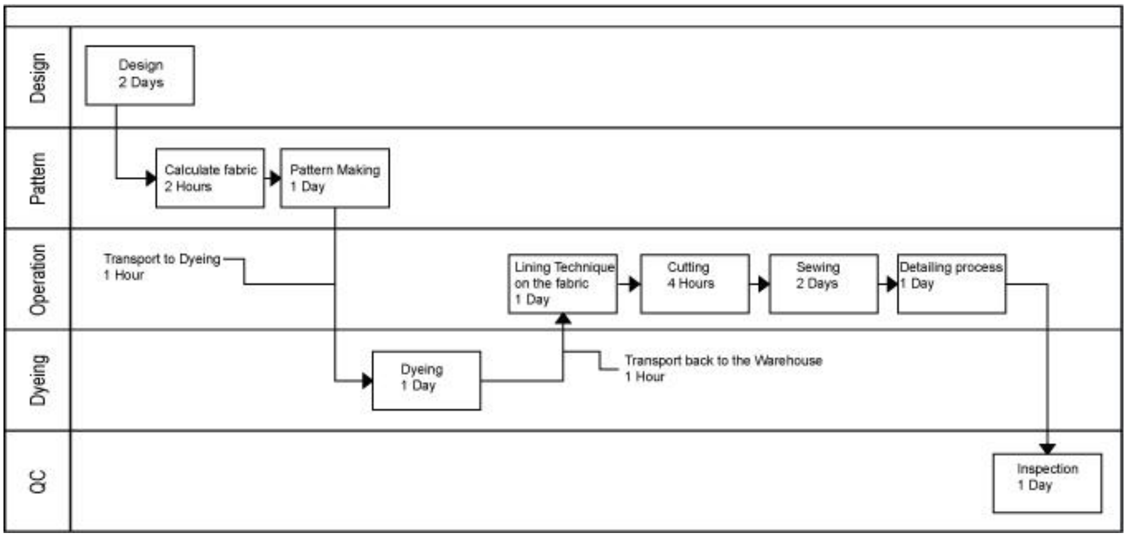

Figure 2.7: The Presentation of Swim Lane Diagram of the Thai Silk Jeans

Source: Komolavanij et al, 2008

Figure 2.7 represents the technique used in order to illustrate the overview for understanding in the production processes of Jeans. The diagram explains that there are five individual lanes as: Design, Pattern, Operation, Dyeing and QC. The design lane process takes 2 days. The pattern lane takes 2 hours for fabric's calculation and 1 day for pattern making. The operation lane consists of lining technique (1 day), cutting (4 hours), sewing (2 days), detailing process (1 day) and transportation to dyeing lane (1 hour). The dyeing lane takes 1 day and then transported back to the warehouse (1 hour) preparing for lining technique on the fabric. After the detailing process is completed, the product will be transported back to the QC lane for inspections which will take 1 day.

Activities	Unit Cost	Costing Variable	Piece	Cost Baht/pc
Design	460 Baht/day	2 Days	50	18.4
Calculate fabric for productions	280 Baht/day	2 Hours	50	1.4
Patern Making	500 Baht/day	1 Day	50	10
Transport to Dyeing	12 Baht/metre	2.4 Metre	1	28.8
Lining Technique on the fabric	50 Baht/metre	2.4 Metre	1	120
Cuttings	233 Baht/metre 1.1914 Bath/unit	1 Hour 1 Hour + 9.0 kWh	1 1	29.1 10.7
Sewing	280 Baht/Day 1.1914 Baht/unit	1.6 Hour 1.6 Hour + 2.0 kWh		56 3.8
QC	233 Baht/day	20 Minute	1	9.7
Meterial Cost			1	528
Total			1	816

Table 2.8: Activity-Based Costing for the Capital Calculation
Source: Komolavanij et al, (2008)

Table 2.8 represents the costing methodology used to provide more in-depth detail into each individual production activity. The total cost of jeans was 816 Thai baht (1 THB equals to 0.02 GBP). The biggest part was the material which took 528 baht. Activity-Based Costing provided much more detail than the traditional method used within the company. In conclusion, at the end of the study, the researchers had identified the major problems in the manufacturer as follows Product Problems, Inventory Management Problems, Management Problems, Marketing Problems and Supply Chain Problems. The mentioned problems were the major objectives to which the key decision maker should pay attention. The researchers also recommended those particular objectives to the key decision maker to consider as short-term, medium-term, and long-term objectives for future planning. According to section 2.6, the stakeholders and the supply chains structure in the Thai silk industry are discussed. It is discovered that there are varieties of the supply chains in order to achieve a final product. Therefore, it is important for every Thai silk manufacturers to better understand their existing suppliers in order to gain an optimal business achievement. The next section discusses supply chain management.

2.10 Supply Chain Management

This section aims at introducing the concepts of the supply chain by giving some of commentary on logistics and supply chains. Then, we focus on some key components of supply chain management. Supply Chain Management (SCM) is a broad topic that has been examined by researchers from different angles in recent years. SCM is "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer et al., 2001). It has also been defined as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally (Supply Chain Management (SCM), 2014).

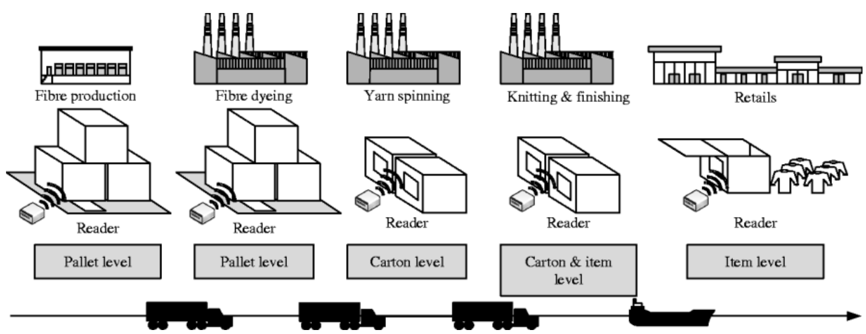

Figure 2.8: Tagging level at different stages in the supply chain
Source: Siu and Kenny, 2009

Figure 2.8 represents the idea how tagging processes work in different stages of supply chain in textiles perspective. A supply chain can be described as a network where facilities and distribution perform the functions of procurement of materials, transformation of these materials into finished products, and then delivered these finished products to final customers. Generally, a supply chain may be defined as the set of parties and agents (such as suppliers (vendor), manufacturers, transporters, buyers, etc.) involved, directly or indirectly, in fulfilling a customer's request (Chopra and Meindl, 2007, Sarmah et al., 2006).

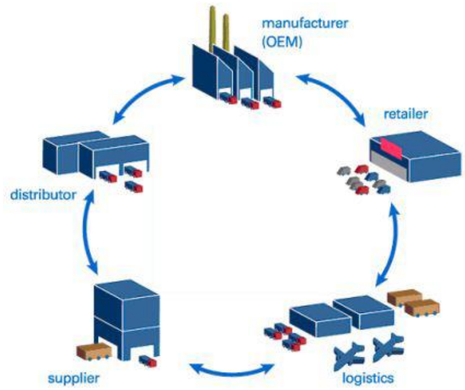

Figure 2.9: Supply Chain Process Flows
Source: Organised by Author

Figure 2.9 represents the circular flow chart of general supply chain which is consisted of supplier, distributor, manufacturer, retailer, and logistics. Mentzer et al. (2001) defined supply chain as a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and information from a source to a customer. To create an effective supply chain, good management is needed to achieve the single or multiple objectives of the supply chain. The key objective of supply chain is to maximise the overall benefit value. The benefit value that supply chains generate, is the difference between what the final product is worth to the customer and the costs the supply chain incurs in filling the customer's requests (Hamontree, 2014).

C.Y. Wong, S. Boon-itt (2008) presents the influence of institutional norms and environmental uncertainty on supply chain integration in the Thai automotive industry. This particular research explores the relationships between environmental uncertainty and supply chain integration and the moderating roles of environmental uncertainty. Based on seven case studies of automotive companies in Thailand, the level of supply chain was found to be associated with environmental uncertainty. The data collection for this research is carried out through semi-structured interviews. In order to increase the reliability of this study, five key semi-structured interview questions was also created based on the definitions and components of the relevant constructs and theoretical framework established at the literature review. The findings found out that institutional norms (e.g. associational network, local government, and local business culture) could improve the level of supply chain integration especially when there was high level of environmental uncertainty (e.g. high transaction cost, and high level of business uncertainty).

Lam and Postle (2006) present the typical problems facing the textile and apparel supply chain as: short product cycle, long production lead-time and forecasting errors for fashion items. The Hong Kong textile and apparel supply chain faces additional problems of distance from customers in the US and European markets, long production lead-times and minimum batch sizes for production, and, recently, elimination of quota restriction in the US market, all of which force them to improve efficiency and enhance competitiveness through supply chain management. This paper fulfils an identified information/resources need and offers practical help to industrial practitioners on the supply chain management for the Hong Kong textile and apparel industry.

Jantaka and Tangjaturasopon (2012) study how to remove barriers of primary activities for supply chain processes of Thai silk products. The method is to interview silk enterprise in a specific zone with total 117 people involved. Data collection is questionnaire based which is specifically designed for the supply chain of Thai silk as: Production or Operation supply chain, Outbound Logistic, and Sales/ Marketing. Finally, the data are analysed to find out the important barrier. The benefit of this research is to identify a variety of barriers in primary activities for the Thai silk supply chains, to be taken by the related agencies for further development.

2.11 Inventory management

Inventory management is one of the basic problems for a company to manage stocks which have been used in many sectors of organisations including business, industries, military etc. (Hamontree, 2014). There are many reasons why the firms have to manage them. The common questions are used for the inventory control and management when the product or service is ordered and how many products or services are ordered (Hadley and Whitin, 1963)?

Inventory can be classified into three types including raw materials, work in progress, and finished goods (Ghiani et al., 2004). An important role that inventory plays in the supply chain is to increase the amount of demand that can be satisfied by having a product ready and available when the customer wants to use it. Another significant role is to reduce costs by utilizing any economies of scale that may exist during both production and distribution. Inventory is a major source of cost in the supply chain and it has a huge impact on responsiveness (Chopra and Meindl, 2007).

The types of inventory depend on the specifics of industry and business thus inventory found in distribution environments (mainly finished goods for resale) are fundamentally different from those found in manufacturing environments (raw materials and work in progress) (Hamontree, 2014). The finished goods are inventory bearing at distribution or buyer's (retailer) site (Muller, 2003).

In the manufacturing site, an inventory deals with raw materials and sub-assemblies. Considerations of what to buy, when to buy it and in what quantities. In the distribution, we are concerned with having the right item, in the right quantity. Issues relating to having the item at the right time and place are often dealt with by simply increasing safety stock on-hand. Having too much inventory is not a good solution because it leads to wasted money and space. However, traditional inventory management used in computing inventory requirements in a distribution environment focused on item and quantity rather than place and time. In manufacturing, we are concerned with having the right item, in the right quantity, at the right time, in the right place (Muller, 2003).

Kwangyeol et al. (2013) suggests that inventory policies can be characterised based on the responsibility for inventory control. In traditional inventory control policies, each member is responsible for his own inventory control and production or distribution ordering activities. One fundamental characteristic and problem that all members in a traditional Supply Chain including retailers, distributors, and manufacturers must solve is just ‘‘how much to order the production system to make (or the suppliers to supply) to enable a Supply Chain echelon to satisfy its customers’ demands.’’ Each member strives to develop local strategies for optimising her own organisational goals without considering the impact of her strategies on the performance of other members. Upstream members do not know actual demand information from the market place because no information is shared between members (see Figure: 2.10). Supply Chain members use only replenishment orders placed by their immediate downstream member to create demand forecasts and inventory plans. In other words, each echelon in the Supply Chain has information only about what their immediate customers want and not on what the end customer wants. Each member of Supply Chain, therefore, replenishes their own inventory by considering their local inventory position.

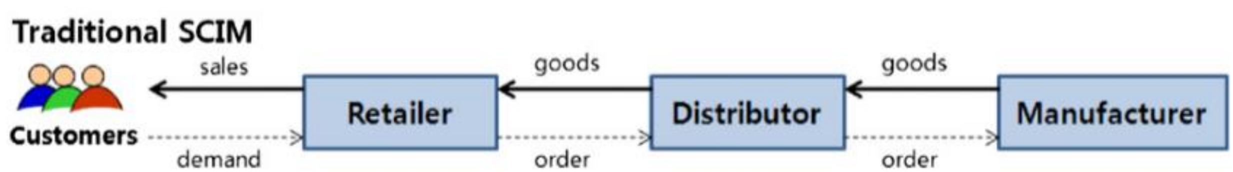

Figure 2.10: Traditional Supply Chain Inventory Management

Source: Kwangyeol et al., 2013

2.11.1 Inventory Optimisation

The inventory is the basic function to protect the supply of goods from demand changes. Since costs are associated with inventories, they need to be dealt with in an effective, efficient, and economic manner. The simple question that inventory theory attempts to answer is “How much inventory should be held?” in order to avoid either inventory overload or shortage in inventory, and also there are two fundamental questions that are derived from the previous one which have to be addressed by inventory optimisation models for optimal inventory control are: “How much inventory should be ordered? And when inventory should be replenished? (Hamontree, 2014).

Promsaka Na Sakolnakorn (2009) presents the management strategy for administration of textile industries in a developing country: case study in Thailand. The purpose of this particular research was to identify significant problems with the manufacturing and inventory management of the textile industry in northeast Thailand and suggest a management strategy that will solve those problems. The objectives of this study were to study the factors affecting the organizational development of textile industries and to explore the guidelines for development of the operation and management of textile industries. The data collection is based qualitative and quantitative methods. Researchers conducted interviews with 18 entrepreneurs in textile industries in northeast Thailand and analyzed the data by doing a content analysis. The findings revealed that there were six influences on the organisational development of textile industries: 1) human resource management, 2) financial performance, 3) knowledge capital, 4) marketing management, 5) supply chain management, and 6) Inventory management.

In terms of an inventory optimisation, the ultimate purpose of inventory management is optimisation of the inventory policy for the whole production-distribution system to minimise total operating inventory costs while maximizing profits and maintaining a high level of customer service (Hamontree, 2014). This means that the objective of optimal inventory control is to make a balance between the conflicting goals. Cavinato and Kauffman (2000) had presented 9 actions that can be considered when thinking of inventory improvement, as shown by table 2.9.

Actions
Work with suppliers to improve communications in the supply chain.
Negotiate lower lead times with suppliers.
Standardize (Substitute for standard parts and Consolidate common part numbers)
Reduce the number of part numbers carried.
Take credit and track your efforts to reduce inventory.
Find ways to reduce surplus and obsolete inventory.
Improve supplier's quality to reduce costs.
Challenge and reduce minimum order quantities.
Improve suppliers on time delivery performance.
Set up a supplier managed inventory programs.

Table 2.9: The set of actions for inventory optimisation
Source: Cavinato and Kauffman, 2000

The actions consist of working with suppliers to improve communications, negotiate with suppliers for lower lead times, standardization, reduce the number of spare part, take credit and track your efforts to reduce inventory, reduce surplus and obsolete inventory, improve supplier's quality to reduce costs, challenge and reduce minimum order quantities, improve suppliers on time delivery performance, and set up a supplier managed inventory programs. These actions will also be undertaken as major analytical choices in the experiment chapter no. 8. The next section will discuss Operational Research (OR) methods that will be considered to contribute supply chain and inventory improvement. (More details can be seen in the Methodology Chapter no. 3).

2.12 Operational Research Methods

In this section, operational research will be discussed regarding its nature and purpose followed by the operational research models that will be used as analytical techniques for the primary data analysis chapters, as follows; Analytical Hierarchy Process (AHP), Data Envelopment Analysis (DEA), and Goal-Programming (GP).

2.12.1 Operational Research

Brans and Gallo (2007), Ormerod and Ulrich, (2013) define OR as a human activity in which OR workers engage with other humans to improve human-activity systems. OR is the use of advanced analytical techniques to improve decision making. It is sometimes known as operations research, management science or industrial engineering. People with skills in OR hold jobs in decision support, business analytics, marketing analysis and logistics planning – as well as jobs with OR in the title (Lancaster University, 2014). Figure 2.11 also represents the nature of OR.

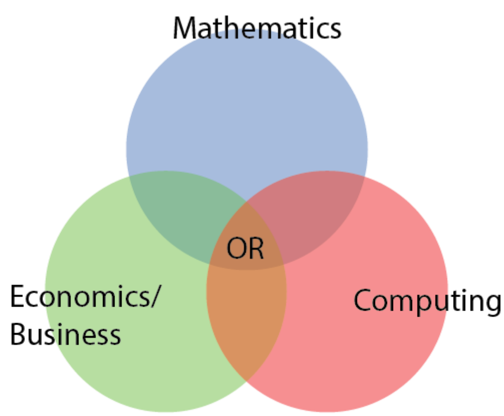

Figure 2.11: The Nature of OR
Source: Organised by Author

Why is OR needed? Because it makes sense to make the best use of available resources. Today's global markets and instant communications mean that customers expect high-quality products and services when they need them, where they need them. Organisations, whether public or private, need to provide these products and services as effectively and efficiently as possible. This requires careful planning and analysis the hallmarks of good OR. This is usually based on process modeling, analysis of options or business analytics (Lancaster University, 2014). Decision making within the real world inevitably includes the consideration of evidence that is based on several criteria, rather than on a preferred single criterion (Beynon, 2002). In business, decision making practices increasingly involve multi-criteria decisions that are made by groups of decision makers (Triantaphyllou, 2000). The solution to a multi-criteria decision problem can provide a recommendation to decision makers who are faced with a choice of Decision Alternatives. Multi-Criteria Decision Making (MCDM) in OR is currently one of the most well-known branches of decision making methodology (PLEA, 2011). The next section represents the analytical techniques used for data and system analysis. This research will use measurement technique and multiple criteria decision making approaches in order to apply them to decision making regarding supply chains and inventory management for the case studies.

2.12.2 ANALYTICAL HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) has been frequently used as a tool for a wide variety of decision-making situations in fields such as government, business, industry, healthcare, and education. It was developed by Saaty (1980) and has been extensively studied and refined since then. PG Public Services (2010) presented that rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

AHP is one type of approach for decision making. It involves structuring the multiple choice of criteria into a set of weights, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives. AHP is to decompose the decision problem into a hierarchy that consists of the most important elements of the decision problem (Saaty and Peniwati, 2008). Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, but they typically use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques (PG Public Services, 2010).

Phusavat and Kanchana (2007) presents competitive priorities of manufacturing firms in Thailand. The purpose of this particular research was to identify competitive priorities, based on the opinions of top executives of manufacturing firms belonging to the Federation of Thai Industry (FTI). The data collection for this research was carried out through a survey in order to gather the opinions of top executives. Ten manufacturers from four industries participated in the study. The analytical hierarchy process (AHP) was selected to analyze the survey responses. The findings found out that there were six criteria selected to reflect competitive priorities: quality, customer-focus, delivery, flexibility, know-how, and costs. The study revealed that the quality, customer-focus and delivery criteria were recognized as important priorities in order to enhance manufacturing firms' competitiveness. The experiences possibly suggest more attention on innovation in order to sustain quality improvement.

Wang et al. (2004) propose an integrated analytic hierarchy process (AHP) and pre-emptive goal programming (PGP) based multi-criteria decision-making methodology to take into account both qualitative and quantitative factors in supplier selection. While the AHP process matches product characteristics with supplier characteristics (using supplier ratings derived from pairwise comparisons), PGP mathematically determines the optimal order quantity from the chosen suppliers.

Krishnendu et al. (2012) presents an integrated approach for selecting an appropriate supplier in the supply chain, addressing the carbon emission issue, using fuzzy-AHP and fuzzy multi-objective linear programming. Fuzzy AHP is applied first for analyzing the weights of the multiple factors. The considered factors are cost, quality rejection percentage, late delivery percentage, greenhouse gas emission and demand. These weights of the multiple factors are used in fuzzy multi-objective linear programming for supplier selection and quota allocation. An illustration with a data set from a realistic situation is presented to demonstrate the effectiveness of the proposed model.

2.12.2.1 The advantages and disadvantages of AHP

Advantages	Disadvantages
• AHP can take into consideration the relative priorities of factors or alternatives and represents the best alternative. • AHP provides a simple and very flexible model for a given problem. • AHP provides an easy applicable decision making methodology that assist the decision maker to precisely decide the judgments. • Either objective or subjective considerations or either quantitative or qualitative information play an important role during the decision process. • Any level of details about the main focus can be listed or structured in this method. By this way the overview of the main focus or the problem can be represented very easily. • AHP has a very wide range of usage like; planning, effectiveness, benefit and risk analysis, choosing any kind of decision among alternatives. • AHP relies on the judgments if experts from different backgrounds; so the main focus or the problem can be evaluated easily from different aspects. • Decision maker can analyze the elasticity of the final decision by applying the sensitivity analyzes. • It is possible to measure the consistency of decision maker‘s judgments. • Computer software help decision makers to apply AHP fast and precisely	• There is not always a solution to the linear equations. • The computational requirement is tremendous even for a small problem. • AHP allows only triangular fuzzy numbers to be used. • AHP is based on both probability and possibility measures. • Rank reversal fact should be considered carefully during the application. It defines the changes of the order of the judgment alternatives when a new judgment alternative is added to the problem. Validity of the rank reversal is still discussed in literature. • AHP has a subjective nature of the modeling process is a constraint of AHP. That means that methodology cannot guarantee the decisions as definitely true. • When the number of the levels in the hierarchy increase, the number of pair comparisons also increase, so that to build the AHP model takes much more time and effort.

Table 2.10: The advantages and disadvantages of AHP

Source: Oguztimur, 2010

2.12.3 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) was originally developed by Charnes et al. (1978) by applying a linear programming technique that converted multiple inputs and multiple outputs into a scalar measure of relative productive efficiency to construct a frontier based on the sample. DEA is a nonparametric method for measuring the efficiency of a decision-making unit (DMU). Any group of entities that receives the same set of the inputs and produces the same set of outputs could be designated as a DMU; it could be a group of people, companies, hospitals, schools, industries, or countries. To determine the relative efficiency of each DMU in the group, DEA collapses inputs and outputs defined by the model into a ratio of a single meta-input and meta-output, and uses methods of linear programming to calculate the efficiency score for each DMU (Samoilenko and Osei-Bryson, 2012). Tyagi at al., (2009) also described that DEA is a linear programming based technique which is applied to assess the efficiency of organisations such as universities, schools, bank branches, hospitals, power plants, police stations, tax offices, prisons, manufacturing units and a set of firms or even practicing individuals such as medical practitioners which often use multiple resources (inputs) to achieve multiple goals (outputs). In addition Talluri, (2000) described that DEA is a multi-factor productivity analysis model for measuring the relative efficiencies of a homogenous set of decision making units (DMUs). The efficiency score in the presence of multiple input and output factors is defined in figure 2.12:

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

$$\text{relative efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}$$

$$\text{relative efficiency} = \frac{\sum_{r}^{s} \mu_r y_{rj}}{\sum_{i}^{m} \nu_i x_{ij}}$$

Figure 2.12: DEA method overview

Source: Organised by author

In DEA analysis, it is generally assumed that there are n production units to be evaluated, using amounts of m different inputs to produce quantities of s different outputs. Specifically, the o^{th} production unit consumes x_{io} units of input i (i = 1 to m) and produces y_{ro} units of output r (r = 1 to s). The o^{th} production unit can now be described more compactly with the vectors (X_o , Y_o), which denote, respectively, the vectors of input and output values for DMU_o (Lin Lai, 2013). Therefore, an orientation of the model to determine the measurement of the efficiency is needed. There are three basic orientations: input, output, and output/input (Lin Lai, 2013).

Chansarn (2008) presents the relative efficiency of commercial banks in Thailand using the DEA approach. The research aims to examine the relative efficiency of Thai commercial banks during 2003 – 2006 by utilizing Data Envelopment Analysis (DEA). The data collection is based on the sample of 13 commercial banks. DEA model was employed under two different approaches in evaluating the relative efficiency of commercial banks in Thailand. The findings reveal that the efficiency of Thai commercial banks via operation approach is very high and stable while the efficiency via intermediation approach is moderately high and somewhat volatile. In term of size, large, medium and small banks, on average, are efficient via an operational approach with the average efficiencies of 100%. However, small banks are the most efficient banks via an intermediation approach.

Weber et al. (2000) presents an approach for evaluating the number of vendors to employ in a procurement situation using a combined multi objective programming (MOP) and Data Envelopment Analysis (DEA) based framework. They applied MOP to calculate the order quantity and used DEA for vendors’ efficiency evaluation. Formulations are presented for both the MOP and DEA models. A case study is presented for a fortune company in a just-in-time (JIT) manufacturing environment.

Wang et al (2008) proposed an integrated AHP–DEA methodology to evaluate bridge risks of hundreds or thousands of bridge structures, based on which the maintenance priorities of the bridge structures can be decided. The proposed AHP–DEA methodology uses the AHP to determine the weights of criteria, linguistic terms such as High, Medium, Low and None to assess bridge risks under each criterion, the data envelopment analysis (DEA) method to determine the values of the linguistic terms, and the simple additive weighting (SAW) method to aggregate bridge risks under different criteria into an overall risk score for each bridge structure. The integrated AHP–DEA methodology is applicable to any number of decision alternatives and is illustrated with a numerical example.

2.12.3.1 The advantages and disadvantages of DEA

Advantages	Disadvantages
No need to explicitly specify a mathematical form for the production function	Results are sensitive to the selection of inputs and outputs.
Proven to be useful in uncovering relationships that remain hidden for other methodologies	You cannot test for the best specification.
Capable of handling multiple inputs and outputs	The number of efficient firms on the frontier tends to increase with the number of inputs and output variables.
Capable of being used with any input-output measurement	
The sources of inefficiency can be analysed and quantified for every evaluated unit	

Table 2.11: The advantages and disadvantages of DEA

Source: Berg, 2010

2.12.4 Goal-Programming (GP)

Goal Programming (GP) is one of the most widely used techniques for multiple criteria decision making (MCDM). Ignizio (1982) states that in GP, the main idea is to provide a satisficing solution and the basic assumption is that if a satisfactory solution is achieved then the resources have been allocated as best as possible, according to the decision maker's desire and preferences (Khorramshahgol, 2012).

GP was originally developed by Charnes and Cooper and extended and improved by Ignizio. Schniederjans (1995) gave a large number of pre-1995 articles relating to goal programming. Jones and Tamiz presented an annotated bibliography of the period 1990-2000. A recent textbook by Jones and Tamiz (2010) gives a comprehensive overview of practical goal programming.

This optimisation technique can be thought of as an extension or generalisation of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimised in an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used. As satisfaction of the target is deemed to satisfy the decision maker(s), an underlying satisficing philosophy is assumed.

2.12.4.1 GP Variants

- Weighted goal programming

If the decision maker is more interested in direct comparisons of the objectives then Weighted or non-pre-emptive goal programming should be used (Adhikari, 2009). In this case all the unwanted deviations are multiplied by weights, reflecting their relative importance, and added together as a single sum to form the achievement function. Weighted GP is used when the decision maker is able to provide relative preferences between goals (direct or pairwise comparison) (Jones and Tamiz, 2010).

- Lexicographic goal programming

The initial goal programming formulations ordered the unwanted deviations into a number of priority levels, with the minimisation of a deviation in a higher priority level being infinitely more important than any deviations in lower priority levels (Adhikari, 2009). This is known as lexicographic or pre-emptive goal programming. Ignizio (1976) gave an algorithm showing how a lexicographic goal programme can be solved as a series of linear programmes. Lexicographic goal programming should be used when there exists a clear priority ordering amongst the goals to be achieved.

- Chebyshev goal programming

For decision makers more interested in obtaining a balance between the competing objectives, Chebyshev goal programming should be used. Introduced by Flavell (1976). This variant seeks to minimise the maximum unwanted deviation, rather than the sum of deviations. This utilises the Chebyshev distance metric, which emphasises justice and balance rather than ruthless optimisation (Adhikari, 2009).

- Extended goal programming

Extended goal programming was introduced by Romero (2001, 2004). It was designed to give a flexible framework into which all major variants of goal programming fit. This variant allows the decision maker to examine the tradeoff between optimisation and balance by parametric analysis.

When constructing a GP model, the procedure starts with specifying a target or aspiration value for each objective, thus transforming all objectives into goals. The resultant objective function, termed achievement function, is then the summation of deviations from these goals. Since it is usually impossible to attain all goals simultaneously, the problem is then to minimise the sum of the deviations from the goals; that is, to minimise the achievement function. A weighted GP model can be shown as follow:

$$\text{MIN a} = \sum_{i=1}^{m} \left(\frac{u_i n_i}{b_i} + \frac{v_i p_i}{b_i} \right)$$

Subject to:

$$f_i(x) + n_i - p_i = b_i \qquad i = 1, \dots, m$$

$$x_j \geq 0 \qquad j = 1, \dots, n$$

$$n_i p_i \geq 0 \qquad i = 1, \dots, m$$

Where:

x_j is the *j*th decision variable,

b_i is a target value for goal *i*,

n_i is the negative deviation from (b_i)

p_i is the positive deviation from (b_i)

u_i, v_i are the weights assigned by the decision makers on the negative and positive deviations, respectively.

$f_i(x)$ is the achieved value for goal *i*.

m is a number of goals

n is a number of decision variables

To obtain weights and priorities for various goals in GP, Khorramshahgol et al (1988) and Gass (1986) suggested using AHP. Khorramshahgol (2012) uses goal programming (GP) and the analytic hierarchy process (AHP), proposes an integrated methodology to aid decision makers in (1) evaluating, screening and selecting the best suppliers from among an exhaustive list of available suppliers and (2) determining the amount to be purchased from the selected suppliers. Along the supply chain, the suppliers, by being situated at the upstream of the chain, play a crucial role in the successful management of the entire (subsequent) members of the chain and can have a significant impact on the efficiency and effectiveness of the activities of the rest of the chain, and ultimately, on the delivery of the desired products/services. Thus supplier selection can certainly contribute greatly to a firm's competitive advantage and its organizational success. This study aims to eliminate the least qualified suppliers and to choose the most efficient ones.

Jadid et al. (2014) proposed a new multi-choice goal programming (MCGP) to solve a supplier selection problems as: a multi-objective optimisation problem with three minimisation objectives: price, rejects and lead-time. In reality, the objectives may have different relative weights. Also, the decision makers may have other preferences such as the purchasing cost not significantly exceeding the budget. One of the main advantages of the proposed model is that it provides the decision makers with more control over their preferences. Oddoye et al. (2009) cited by Li et al. (2009) detail a GP model to analyse the performance of a Medical Assessment Unit (MAU) and find solutions for bed allocation for patients with minimum delay. Oddoye et al. (2009) combine queuing and goal programming to evaluate the trade-off between resource availability and patient flow metrics such as wait time and cycle time in a multistage medical assessment unit in the UK. The authors use simulation to identify different scenarios for removing patient flow bottlenecks and then submit the results of each simulated scenario to a goal program. The goal program then selects the scenario that best reflects the organization priorities.

2.12.4.2 The advantages and disadvantages of GP

Advantages	Disadvantages
Goal programming consists of multiple variants which allows for the modelling of a wide range of underlying decision maker preference functions.	More time and thought, is required in the construction of the model.
Useful in situations where the multiple goals are conflicting and cannot all be fully achieved.	More decistion-maker involvement is required, that is in the establishment of aspriation levels and weightings.
Used to "satisfice" rather than "optimize" the problem. In linear programming, what one wants is to optimize the solution. But in using the goal programming, the goal may be incorporated into the model at a value that is judged to be satisfactory, not necessarily opimal.	The subjectivity regarding the weights given to goal deviations may be off concern.
Appropriate to find a satisfactory solution where many objectives or goals are to be considered	

Table 2.12: The advantages and disadvantages of GP

Source: Ahmad et al, 2005, Adapted by author.

2.13 Summary of Gaps in Research Literature

As far as the Silk sections were reviewed, the basis of the key issues and constraints impacting on the silk industry in Thailand are highlighted. A set of priorities for action and investment options can be recommended to be the key issue in need of improvement. In addition, according to the mentioned case studies in the literature, there were recommendation points where the key constraints that caused concern are Product Problems, Inventory Management Problems, Management Problems, Marketing Problems, Supply Chain Problems. Promsaka Na Sakolnakorn (2009) also presented that supply chain management and Inventory management were discovered to be key areas for improvement in the industry.

Although the literature reviewed interesting problems of coordination in the Thai silk's industry and different research areas, there is still no known research project in Thailand which truly studies in-depth regarding the current major problems and constraints in the industry. Graham (2011) also pointed out that there is no specific study on the production chains of the Thai silk industry at the time of writing. Thai silk producers are currently in a worrying economic position. The old global Multi-Fiber Arrangement (MFA), which expired in 2005, set export limits to wealthy countries on textiles (Yearman and Gluckman, 2005). However, with its expiration, Thailand's National Economic and Social Development Board and the World Bank (2005) warn that Thai silk is highly uncompetitive in comparison to Chinese and other imported fabrics. Contemporary logistics and supply chains are required for the expansion of the Thai silk industry (Thailand Textile Industry, 2009). Therefore, it becomes clear that having more research in supply chains will improve the industry. The studying of literature also discovers that there is still no critical research in terms of supply chains and inventory managements for the Thai Silk industry. The contributions of this research will benefit Thailand' textile and silk industry. Thus, this research will engage with the selected key constraints mentioned in the literature. Supply Chain and Inventory Management will be the main focal areas to be studied in the thesis

Chapter 3 RESEARCH METHODOLOGY

3.1 Research design and data description

The conducted research is both quantitative and qualitative in nature. Therefore, the research design and theoretical framework will employ both quantitative and qualitative techniques. To obtain the desired information, a semi-structured interview, open and close-ended questionnaire will be developed to enable key questions to be answered, such as companies' existing logistics strategies, major barriers, and relationships with the Logistics Service Providers in the Thai silk's logistics industry. Data analysis techniques will be employed for the interpretation of collected primary and secondary data. The research will employ case studies of Thai silk manufacturers.

3.2 Research Structure

After discussing research design and data description in the previous section, the research process is described in this section. The framework of the research procedures that are used in this study and the tasks of each stage are summarised and presented in Figure 3.1.

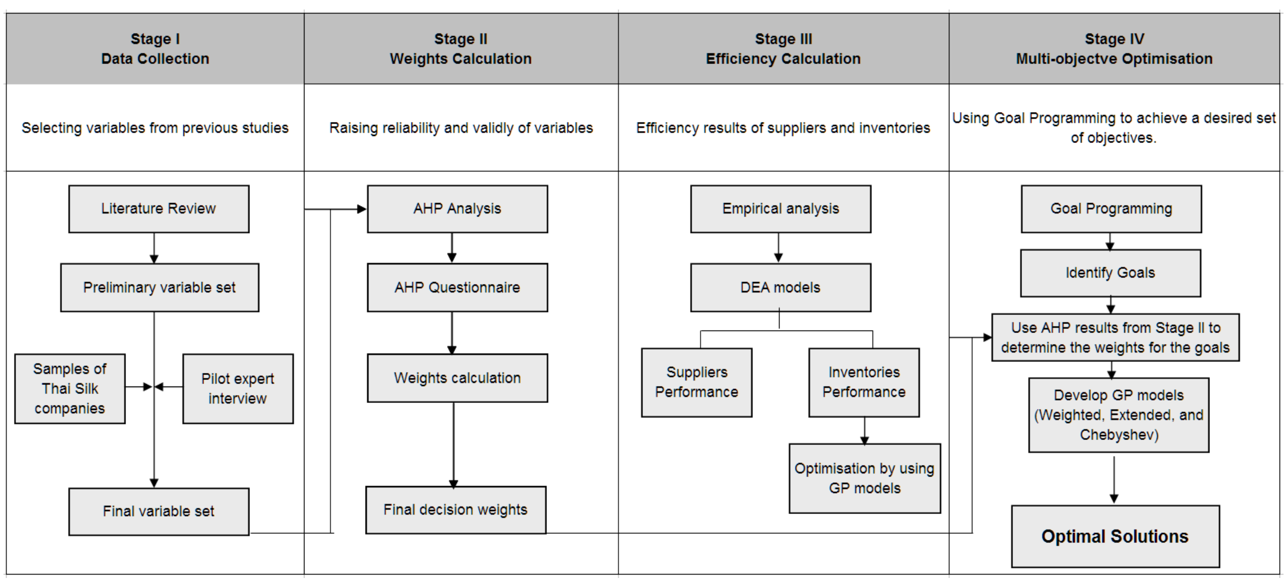

Figure 3.1 Framework of the Research Structure

Source: Organised by author

According to figure 3.1, stage I is data collection for the variable set (detailed in Chapter 4). The thesis first begins with a literature review to find out the preliminary variable set, which reveals the existing problems in Thai silk factories. Supply chain management and Inventory management are undertaken to be focal areas for further analysis. Samples of Thai silk companies and pilot interviews are employed in order to obtain the actual variable set used in the AHP questionnaire in Stage II. Stage II is the weight calculation using the AHP method. This process provides key decision makers' preferential weights considering each of the given variables obtained from Stage I. Those weighting results are also used in Stage VI to determine weights for the goal-programming analysis. Stage III is efficiency analysis using DEA method for manufacturers' exiting suppliers and inventory management. This process provides key decision makers a clear vision to know inefficient areas that they may consider for improvements. Finally, stage VI is for multi-objective optimisation where inventory management is undertaken using Goal-programming. This process aims to suggest key decision makers solutions for inventory optimisation (also detailed in Table 2.9). Therefore, the OR models used in the thesis are as follows:

1. Analytical Hierarchy Process (AHP) is used for optimal decision making for manufacturers' owner or key decision makers.

2. Data Envelopment Analysis (DEA) is used for measuring efficiency in manufacturers (existing suppliers and inventory management),

3. Goal programming (GP) is used for optimising planning decisions in the presence of multiple conflicting objectives regarding inventory management, since each of manufacturers have multiple decision choices to solve their existing problems.

Computer software LINGO version 14.0 and Microsoft Excel 2010 edition will be used to analyse data collected from the above algebraic models. Generally speaking, AHP is a method that uses both semi-structured interviews and structured interviews to acquire data (Lin Lai, 2013). The next sections (3.3 and 3.4) will be discussed regarding semi-structured and structured interviews.

3.3 SEMI-STRUCTURED INTERVIEW

Interviews are generally believed to be an appropriate method for an exploratory study to find out what is happening and to seek new insights (Robson 2002, Saunders et al. 2007). While in unstructured interviews, there is no predetermined list of questions to work through, in semi-structured interviews, the researcher has a list of questions and themes to be covered although these may vary from case to case. This means that the researcher can omit some questions in particular interviews and may change the order of questions depending on the flow of the conversation (Saunders et al. 2007). This research employed a semi-structured interview because the situations which the interview aimed to explore were relatively constrained. In other words, the exploration has to be made within the research questions. However, the numbers of questions were minimised in order to make the interview more flexible and less directive and to obtain deeper understanding of interviewees' perceptions. One of the main objectives of conducting interviews is to ensure the validity and the reliability of the variables of the evaluation system. To address subjectivity concerns, which is often one of the major criticisms faced by qualitative research. this study has applied the AHP method during the process of variable selection.

The semi-structured interview scheme allowed for the addition of more questions and asking these questions differently depending on the responses from interviewees. The interviews were recorded by note-taking and recording and then transcribed for analysis. Sampling interviewees and analysis are addressed in Chapter 4. Bryman and Bell (2007) indicated that clear-cut rules about how qualitative data analysis should be carried out have not been developed because qualitative data takes the form of a large corpus of unstructured textual material. However the basic concept for qualitative data analysis is categorisation and characterisation (Saunders et al. 2009). Several of the aspects the interviewees described in the interviews can be sorted into various categories.

3.4 STRUCTURED INTERVIEW

Structured interviews are often designed to emphasise the greater generality in the formulation of the interviewer's concerns of the informants' perspectives (Bryman, 2008). A structured interview can be conducted in a structured questionnaire. The advantage of structured interviews lies in the uniformity of the interviewees' behaviour; hence, other people than the researcher are able to replicate the interview in a similar situation (Ghauri and Grønhaug, 2002). The aim of a structured interview is to gather data from a statistically representative sample of the population in a controlled environment (Bryman, 2008).

Due to the quantitative nature of the questions, a structured interview is designed to categorise, select and rank the appropriateness of variables that are adopted in an evaluation system. In order to avoid any misunderstanding of the question, the researcher provides the definition of each variable in the questionnaire in order to increase both response and completion rates. The data from structured interviews can then be analysed through a quantitative approach to identify any significant differences between variables, such as through the use of ANOVA (Analysis of Variance) or other statistical methods. The results of the data analysis can help the researcher identify the most appropriate variables. In this research, the ANOVA method is not used to analyse the questionnaires, instead AHP analysis is used to analyse the questionnaire. AHP has been frequently used as an analytic tool for decision-making situations in fields such as government, business, industry, healthcare, and education. In this research, AHP is used in order to obtain optimal solutions in decision making for manufacturers' key decision makers.

According to Saunders et al. (2007), there are various types of questionnaire survey methods that should be taken into account when implementing this specific method (see Figure 3.2).

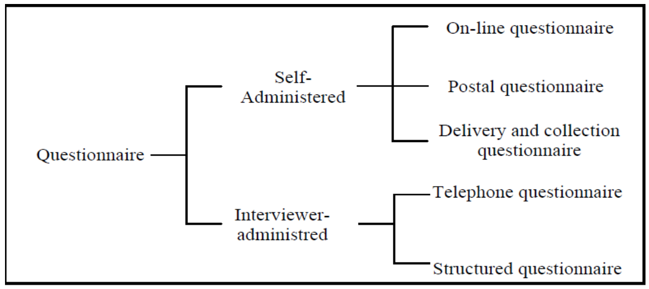

Figure 3.2: Methods of questionnaire administration

Source: Saunders et al. 2007.

There are two main forms of questionnaires, namely: self-administered questionnaire sand interviewer-administered questionnaires. The main difference between these two forms is the involvement of an interviewer (Maylor and Blackmon 2005). The flexibility of an interviewer-administrated questionnaire is that it focuses on a specific subject and the possible extension of its meaning. The interviewer-administrated questionnaire enables researchers to gain more freedom to probe beyond the answer through a form of dialogue with the respondent and, therefore, affords them the opportunity to collect additional information (May, 2001; Bryman and Bell, 2007).

This study is aimed at the development of Thailand's silk industry, and in order to enhance reliability and validity of the variables, the AHP method is employed to acquire the weight of individual variables, DEA is adopted to conduct efficiency analysis of each individual variable, and data collection for GP models are also adopted in order to implement an analysis. Therefore, two forms of data collection processes are used. The first is a semi-structured survey, and the second is a questionnaire survey. Semi-structured survey helps the author conduct a pilot study that can acquire expert opinions to enable the establishment of evaluation variable sets that are obtained by means of in-depth interviews. Questionnaire survey intended to obtain the weight of each variable resulting from handing out an AHP questionnaire (or by conducting so called structured interviews). In addition, some of secondary data in the literature regarding supplier selection and inventory management are also used in this research when undertaking DEA and GP analysis.

3.5 The Case Study Method

The case study method is particularly useful to employ when there is a need to obtain an in-depth appreciation of an issue, event or phenomenon of interest, in its natural real-life context. It is an established research design that is used extensively in a wide variety of disciplines, particularly in the social sciences (Crowe, 2011).

Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. Researchers have used the case study research method for many years across a variety of disciplines. Social scientists, in particular, have made wide use of this research method to examine contemporary real-life situations and provide the basis for the application of ideas and extension of methods (Yin, 1984). Yin has written about case study research and suggested techniques for organizing and conducting the research successfully. This overview to case study research draws out the six steps that should be used:

1. Determine and define the research questions
2. Select the cases and determine data gathering and analysis techniques
3. Prepare to collect the data
4. Collect data in the field
5. Evaluate and analyze the data
6. Prepare the report

In conclusion, case studies are complex because they generally involve multiple sources of data, may include multiple cases within a study, and produce large amounts of data for analysis. Researchers from many disciplines use the case study method to build upon theory, to produce new theory, to dispute or challenge theory, to explain a situation, to provide a basis to apply solutions to situations, to explore, or to describe an object or phenomenon. The advantages of the case study method are its applicability to real-life, contemporary, human situations and its public accessibility through written reports. Case study results relate directly to the common readers, everyday experience, and facilitate an understanding of complex real-life situations (Leon, 2012).

3.6 Conclusions

According to the study of the Thai silk industry with regard to its supply chains, it is discovered that there are still exiting problems in some areas that need to be improved. Those particular problems can be seen from the mentioned case study of the particular Thai silk manufacturer (Classic Model Ltd.). In the literature regarding the major markets of the textile industry, it is also discovered that Thailand seems to keep well in trading balance with almost a hundred percent from the major markets, except from China with whom Thailand has a negative balance. There are recommendation points regarding the key constraints had been concerned as; Product Problems, Inventory Management Problems, Management Problems, Marketing Problems, Supply Chain Problems.

In order to improve two of those mentioned problems, which are “Supply Chain and Inventory”, this research will then establish efficiency analysis of the prototyped procedures undertaken by the participating companies. Asking for opinion from the Key Decision Makers in the industry will provide the beneficial results from the creation of optimal solutions with regard to their preferences. Conclusions will be drawn with respect to the case studies and to the supply chains and inventory management of the Thai silk industry in general. The results will be used to suggest improvements in the decision making process and configuration of the overall supply chains. This will link to the best practice framework that might be applied with the particular companies further, depending on key decision makers’ demand. The knowledge from the literature regarding the exiting Operational Research (OR) models will be incorporated in order to adapt the advantageous elements to help improve the participating manufacturers and Thailand’s silk industry.

Chapter 4 Decision Making Analysis using the Analytic Hierarchy Process (AHP)

Introduction

The previous chapter (Research Methodology) provided an extensive explanation of the methodological tools and analysis methods employed in this research. The aim of this chapter is to present the findings, analysis, and results of the AHP questionnaire. Before discussing data analysis, a pilot study must be undertaken in order to have all variables within the focal research areas (as presented in 4.1, 4.2, and 4.3). This chapter includes two main sections for each individual case study. The first section addresses the results of the AHP being applied in supplier selection of the case studies. The second section presents the AHP being applied with inventory management of the case studies. It then concludes with a brief summary of the analysis of this research. The results will be shown by highlighting three out of the eight companies. (the rest can be seen in appendix B)

4.1 PRELIMINARY EVALUATION VARIABLES

According to Figure 3.2 (Framework of research procedures), the preliminary variable set is going to be established in Stage I. It was revealed in the literature review (2.3) that the two focal areas manufacturers must consider in order to improve their efficiency are: Supply Chain and Inventory Management. Therefore, the preliminary variables can be classified into two main hierarchies, which include the decisions in supplier selections and inventory management (in the real world case studies of the chosen silk manufacturers located in Thailand).

4.2 Conducting Pilot Studies

The aim of conducting pilot interviews is to ensure the validity and reliability of the preliminary variables. To address the concern of subjectivity, the AHP method was used after the process of selecting the variables. Following the guidelines of the research framework (see figure 3.1), the expert was invited to join the individual semi-structured interviews (see figure 4.1 and 4.2).

Figure 4.1: A Formal Meeting with the Chairman of Jim Thompson
Source: Organised by author

In order to have a better understanding of the Thai silk industry and to collect all the final variable sets for data analysis, a pilot expert interview was required. By having the supportive cooperation with Rajamangala University of Technology Thanyaburi (RMUTT) and The Queen Sirikit Department of Sericulture, the author was having a great opportunity to have a meeting with the Chairman of Jim Thompson company on 24th December 2012 (as mentioned in the literature 2.5). The discussion topics were about some issues in supply chains, imports and exports, and computer software for inventory management.

Figure 4.2: Factory tour and Pilot expert interview at Hong Seng Knitting Co., Ltd,
Source: Organised by author

In order to gain an idea how modern Thai's garment and textile manufacturers run their business, factory tour and pilot expert interview were also achieved by cooperation from RMUTT to visit one of the well-known manufacturers named "Hong Seng Knitting Co., Ltd.". The discussion topics were about how they manage their large inventory and how are they dealing with multiple suppliers effectively. The next section will then represent the final variable sets within the specific criteria.

Main Criteria	Sub Criteria	Definition of the criteria
Supplier Selection	Product Quality	The quality rating of the product or raw material produced by the suppliers.
	Service Level	The performance rating that the manufactures feel for their suppliers.
	Management	The management rating of how manufacturers feel for their suppliers.
	Financial Flow	The flow rate in finances that manufacturers feel for their suppliers.
Decision in Inventory Management	Inventory Cost	The total cost of inventory for one particular product.
	Inventory Space	The stocking space used for one particular order (in squre metre).
	Budget Constraint	The total budget for one particular order.
	Delivery Time	On-time delivery rates to their customers.
	Turnover rate	The number of times inventory is sold or used in a time period.

Table 4.1: The final variables of the Thai Silk Industry

Source: Organised by author

Table 4.1 represents the final variables collected from the expert interview. The main criteria are supplier selection and decision in inventory management. Supplier selection is the process by which firms identify, evaluate, and contract with suppliers. The supplier selection process deploys a tremendous amount of a firm's financial resources. In return, firms expect significant benefits from contracting with suppliers offering high value (Beil, 2009). The sub-criteria of supplier selection in this research consists of product quality, service level, management, and financial flow. In terms of inventory management, a major issue in supply chain inventory management is the coordination of inventory policies adopted by different supply chain actors, such as suppliers, manufacturers, distributors, so as to smooth material flow and minimize costs while responsively meeting customer demand (Giannoccaro, 2002). The decision variables in inventory management in this research consists of inventory cost, inventory space, budget constraint, delivery time, and turnover rate. All definitions are given in table 4.1.

4.3 Questionnaire Design and Analysis Methods

After constructing an AHP hierarchy of the Thai silk efficiency evaluation, in stage II (see figure 3.1), a structured interview and data collection (AHP questionnaire) were applied in order to explore the weights analysis of each variable. A questionnaire entitled "Quantitative and Qualitative Analysis of the Thai Silk Industry" was devised based on the hierarchy shown in Table 4.1. This questionnaire was designed into two major sections. The first section was the qualitative questions where general information as; company information, supply chains, logistic partners, inventory management, required to be answered. This section contributes to understand the characteristics of the manufacturers and to obtain numerical information regarding their inventory for further calculations in the DEA analysis (see Chapter 6). The second section concerns the AHP pair-wise comparisons. The measurements were made based on the standard scale from 1 to 9. The definition of each scale will be shown in Table 4.3 and the questionnaire is attached in Appendix A.

In stage II, the data collection was comprised of gathering responses from 8 managing directors from different Thai silk prominent. All respondents were given a clear instruction date and prior of the appointments for an interview and filling out the questionnaire. The list of participated manufacturers is presented in Table 4.2 below;

Manufactures	Date
Shinawatra Thai silk co. ltd	9th July 2013
Kumpor co. Ltd.	18th July 2013
Classic Model co. Ltd.	22nd July 2013
PNL co. ltd	30th July 2013
Watchara Thai Silk co. ltd	8th August 2013
Chattong Thai Silk co. ltd	9th August 2013
Chalieo Thai Silk co. ltd	12th August 2013
Paothong Thai Silk co. ltd	15th August 2013

Table 4.2: List of Participated Thai Silk Manufactures

Source: Organised by author

4.3.1 AHP PROCESS

This section presents the overall process for AHP. Its main characteristic is that it is based on pairwise comparison judgments. The operational process is illustrated in Figure 4.3 below.

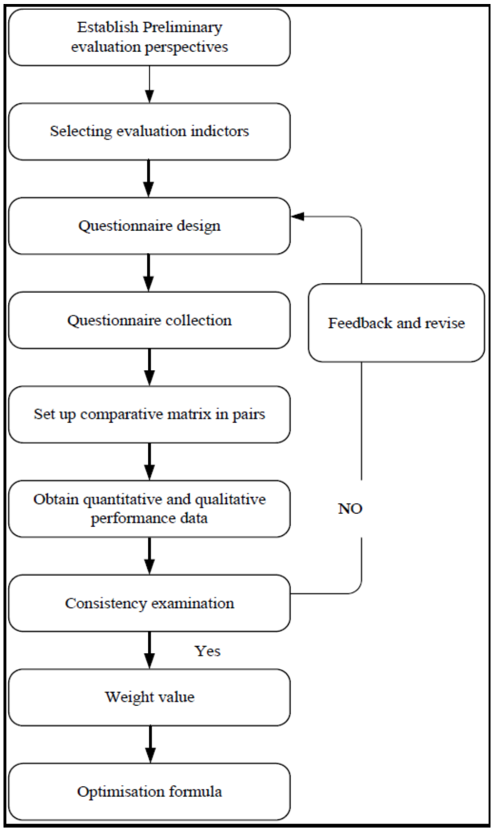

Figure 4.3: The operational process in AHP

Source: Lin Lai, 2013

Firstly, all necessary variables must be identified. Secondly, a questionnaire based on AHP method is developed. Key decision makers answers on a 1-9 rating scale for the pairwise comparisons in the AHP are utilised. Thirdly, a set of weights from the answers of the key decision makers is obtained. Fourthly, a consistency examination must be undertaken in order to measure a reliability of the data obtained from the questionnaire collection and appropriate rectification action taken in the case of excessive inconsistency.

Intensity of Importance	Definition	Explanation
1	Equal importance.	Two activities contribute equally to the objective.
2	Weak or slight.	
3	Moderate importance.	Experience and judgement slightly favour one activity over another.
4	Moderate plus.	
5	Strong importance.	Experience and judgement strongly favour one activity over another.
6	Strong plus.	
7	Very strong or demonstrated Importance.	An activity is favoured very strongly over another; its dominance demonstrated in practice.
8	Very, very strong.	
9	Extreme importance.	The evidence favouring one activity over another is of the highest possible order of affirmation.

Table 4.3: The fundamental scale of absolute numbers

Source: Saaty, 2008

Saaty (1980) constituted a measurement scale for pair-wise comparisons. In addition, in order to create a contrast indicating the degree to which one criterion is more important than another, a scale of numbers (see Table 4.3) is settled. The values of 1, 3, 5, 7, and 9, in the original 1-9 scale by Saaty (2008), represent equal importance, weak importance, essential importance, demonstrated importance, and extreme importance, respectively; while the values 2, 4, 6, and 8 are used to compromise between the values referenced above. In about thirty years ago, Saaty tested the 1-9 scale, the index scale and about twenty other scales when he wanted to choose a suitable ratio sale for the pairwise comparisons in the AHP (Saaty, 2008). Based on the testing results, the 1-9 scale was accepted by the AHP. Since then the 1-9 scale has become the most widely used ratio scale in the AHP. Along with the development of the AHP decision making theory, the 1-9 scale has been used for over 30 years (Zhang et al, 2009). There are five main steps in the AHP (Saaty 2008):

Step 1: Define the decision object.

Step 2: Classify the variables which affect the decision and build a multi-level structure.

Step 3: Make comparisons between each criterion in an upper level and the same criterion in the level below it in terms of relative importance.

Step 4: To calculate the importance degree, the normalisation of the geometric mean method is used to determine the important degrees of the DMs requirements (Escobar et al. 2004).

Step 5: The final step is to test the pairwise comparison's consistency through calculation, modifying it if necessary in order to get an acceptable consistency.

- Calculate CI (which stands for Consistency Index, λmax) using the maximum eigenvalue of the pair-wise comparison matrix, n as the size of matrix:

$$CI = {\lambda_{max} - n}/{n - 1} \qquad (4.1)$$

$$CR = {CI}/{RI} \qquad (4.2)$$

In Equation (4.1), if CI = 0, then the evaluation for the pair-wise comparison matrix is implied to be completely consistent. Generally, a Consistency Ratio (CR) (see Equation 4.2) can be used as a guide to check for consistency. Table 4.4 then shows the order of the matrix and the average RI, which is used to calculate Equation (4.2). The random index for shown in table 4.4

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 4.4: Average Random Index (RI) for corresponding matrix size

Source: Saaty, 2008

The AHP scoring process is then checked for consistency. Saaty (1990) proposed what is called Consistency ratio (CR), which is a comparison between Consistency Index (CI) and Random Consistency Index (RI), or in formula. If the value of Consistency Ratio is smaller or equal to 0.1 (10%), the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to consider revising our subjective judgments; otherwise, the questionnaire has to be returned for re-answering or resolved with other formula (a method for dealing with inconsistencies in pairwise comparisons), which improves the reliability of the weight.

4.4 Experiments

This section discuss the analysis of primary data using the AHP method applied with the manufacturers; Shinawatra Thai silk, Classic Model, and Paothong Thai Silk. The analytical tools used are AHP calculation software developed by Senshu University Japan (Takahagi, 2005) and cross checked with Microsoft Excel AHP solver (developed by Author). Two major sections of Supplier Selection and Decisions in Inventory Management are used.

4.4.1 Shinawatra Thai silk

4.4.1.1 Supplier Selection Analysis of Shinawatra Thai silk

Decision Variables	Original Rating				Weights	C.I.	C.R.
	P.Q	S.L.	M	F.F.			
Product Quality	1	1	4	4	0.37	0.12	0.13
Service Level	1	1	5	5	0.42		
Management	0.25	0.2	1	5	0.15		
Financial Flow	0.25	0.2	0.2	1	0.06		

Table 4.5: The Results of Supplier Selection of Shinawatra Thai silk

Source: Organised by author

In table 4.5, there are four variables considered as follows; product quality, service level, management, and financial flow. P.Q, S.L, M, and F.F are the short forms of the mentioned variables. CI = 0.12 and CR = 0.13, they were both considerably higher than 0.1. Among these decision variables, “Service Level” is found to be the most important variable (0.42).

4.4.1.2 Decision in Inventory Management Analysis of Shinawatra Thai silk

Decision Variables	Original Rating					Weights	C.I.	C.R.
	I.C.	I.S.	B.C.	D.T.	T.R.			
Inventory Cost	1	4	1	0.33333	0.25	0.17	0.24	0.22
Inventory Space	0.25	1	1	1	0.33333	0.11		
Budget Constraint	1	1	1	3	1	0.23		
Delivery Time	3	1	0.33333	1	1	0.20		
Turnover rate	4	3	1	1	1	0.29		

Table 4.6: The Results of Decision in Inventory Management of Shinawatra Thai silk

Source: Organised by author

In table 4.6, there are five variables considered as follows; inventory cost, inventory space, budget constraint, delivery time, and turnover rate. I.C, I.S, B.C, D.T, and T.R are the short forms of the mentioned variables.CI = 0.24 and CR = 0.22, they were both considerably higher than 0.1. Among these decision variables, “Turnover rate” is found to be the most important variable (0.29).

Considering the data presented, the results in the comparison matrices however are slightly unreliable. A method for dealing with inconsistencies in pairwise comparisons (detailed in Chapter 5) will be used in order to improve those values.

4.4.2 Classic Model co. ltd

4.4.2.1 Supplier Selection Analysis (Classic Model co. ltd)

Decision Variables	Original Rating				Weights	C.I.	C.R.
	P.Q	S.L.	M	F.F.			
Product Quality	1	0.11	9	9	0.23	0.44	0.49
Service Level	9	1	9	9	0.68		
Management	0.11	0.11	1	0.11	0.03		
Financial Flow	0.11	0.11	9	1	0.08		

Table 4.7: The Results of Supplier Selection of Classic Model co. ltd,
Source: Organised by author

CI = 0.44 and CR = 0.49, they were both considerably higher than 0.1. Among these decision variables, “Service Level” is found to be the most important variable (0.68).

4.4.2.2 Decision in Inventory Management Analysis (Classic Model co. ltd)

Decision Variables	Original Rating					Weights	C.I.	C.R.
	I.C.	I.S.	B.C.	D.T.	T.R.			
Inventory Cost	1	0.1	1	0.1	1	0.05	0.38	0.34
Inventory Space	9	1	9	0.1	1	0.21		
Budget Constraint	1	0.1	1	0.1	1	0.05		
Delivery Time	9	9	9	1	1	0.54		
Turnover rate	1	1	1	1	1	0.15		

Table 4.8: The Results of Decision in Inventory Management of Classic Model co. ltd,
Source: Organised by author

CI = 0.38 and CR = 0.34, they were both considerably higher than 0.1. Among these decision variables, “Delivery Time” is found to be the most important variable (0.54).

Considering the data presented, the results in the comparison matrices however are slightly unreliable. A method for dealing with inconsistencies in pairwise comparisons (detailed in Chapter 5) will be used in order to improve those values.

4.4.3 Paothong Thai Silk co. ltd

4.4.3.1 Supplier Selection Analysis (Paothong Thai Silk co. ltd)

Decision Variables	Original Rating				Weights	C.I.	C.R.
	P.Q	S.L.	M	F.F.			
Product Quality	1	8	9	9	0.68	0.39	0.44
Service Level	0.13	1	0.13	8	0.08		
Management	0.11	8	1	8	0.22		
Financial Flow	0.111	0.13	0.13	1	0.03		

Table 4.9: The Results of Supplier Selection of Paothong Thai Silk,
Source: Organised by author

CI = 0.39 and CR = 0.44, they were both considerably higher than 0.1. Among these decision variables, “Product Quality” is found to be the most important variable (0.68).

4.4.3.2 Decision in Inventory Management Analysis (Paothong Thai Silk co. ltd)

Decision Variables	Original Rating					Weights	C.I.	C.R.
	I.C.	I.S.	B.C.	D.T.	T.R.			
Inventory Cost	1	9	9	0.11	0.13	0.11	0.56	0.50
Inventory Space	0.11	1	9	0.13	0.13	0.05		
Budget Constraint	0.111	0.11	1	0.13	0.13	0.02		
Delivery Time	9	8	8	1	9	0.59		
Turnover rate	8	8	8	0.11	1	0.24		

Table 4.10: The Results of Decision in Inventory Management of Paothong Thai Silk, Source: Organised by author

CI = 0.56 and CR = 0.50, they were both considerably higher than 0.1. Among these decision variables, “Delivery Time” is found to be the most important variable (0.59).

Considering the data presented, the results in the comparison matrices however are slightly unreliable. A method for dealing with inconsistencies in pairwise comparisons (detailed in Chapter 5) will be used in order to improve those values.

4.5 Summary of AHP analysis

This chapter discussed regarding how preliminary variables were obtained in Thailand by conducting the pilot studies. The final variable sets were then obtained. The main criteria are supplier selection and decision in inventory management. The sub-criteria of supplier selection consists of product quality, service level, management, and financial flow. The sub-criteria of decision in inventory management consists of inventory cost, inventory space, budget constraint, delivery time, and turnover rate. Questionnaire design and analysis methods are then presented by which data collection is completed by response from managing directors from different Thai silk manufacturers. The use of AHP judgement scales in this research and their application were also described in this chapter. From a comparison of the results using a 1-9 scale, it appeared that different scales can obtain different weights (see table 4.11 below).

Supplier Selection			
	Shinawatra	**Classic Model**	**Paothong**
Product Quality	0.37	0.23	0.68 ✓
Service Level	0.42 ✓	0.68 ✓	0.08
Management	0.15	0.03	0.22
Financial Flow	0.06	0.08	0.03
CR	0.13	0.49	0.44

Decision in Inventory Management			
	Shinawatra	**Classic Model**	**Paothong**
Inventory Cost	0.17	0.05	0.11
Inventory Space	0.11	0.21	0.05
Budget Constraint	0.23	0.05	0.02
Delivery Time	0.20	0.54 ✓	0.59 ✓
Turnover rate	0.29 ✓	0.15	0.24
CR	0.22	0.34	0.50

Table 4.11: Summary Table of AHP Analysis
Source: Organised by author

In terms of Supplier Selection analysis, the results of AHP indicated that expert from Shinawatra Thai silk and Classic Model co. ltd prioritized “Service Level”. Paothong’s was “Product Quality”. In terms of Decision in Inventory Management analysis, the results of AHP indicated that Shinawatra Thai silk prioritized “Turnover rate”. Classic Model co. ltd, and Paothong Thai Silk co. ltd prioritized “Delivery time”. However, the received CI and CR values were all greater than 0.1 (10%), therefore, the results in this comparison matrix were unreliable. The next chapter will discuss a method for dealing with inconsistencies in pairwise comparisons, which can be used to reduce those unacceptable CI and CR results.

4.6 Conclusion

In this chapter, AHP provides quantitative weights to be used in decision support. It does not, however, include statistical assessment of the uncertainty of the results. The measure of the consistency of the comparisons made, the consistency ratio, resulting from AHP calculations provides no direct information about the uncertainty of the weights obtained. Other methods for analysing uncertainties in pairwise comparisons had been presented. Mikko et al. (2000) suggested a variance components modeling approach, where uncertainty or variation of the judgments in the case of multiple judges can be divided into three parts: (1) interpersonal variation around the population mean; (2) possible shared logical inconsistency of the judgments among the judges; and (3) residual uncertainty. Gonzalez and Romero (2003) presented the method of using Goal Programming as an attractive and flexible tool for a distance-based framework for analysing this kind of compatibility to solve inconsistencies in pairwise comparisons.

According to the experiences of this experiment, the results of AHP were promising. Making pairwise comparisons forces the decision maker to think over the weights of the factors and to analyse the situation more precisely and in more depth. The method of AHP being applied with the case studies provides an effective framework for learning about strategic decision support in numerous situations. It can also be used as a tool in communication and education in decision making processes where multiple decision makers or judges are involved.

Chapter 5 The method for dealing with inconsistencies in pairwise comparisons

Introduction

The previous chapter (Chapter 4) provided the results of Analytic Hierarchy Process methods applied in the three samples of the case studies. As mentioned in the previous chapter, if the Consistency Index (CI) and Consistency Ratio (CR) are less than 0.1 (10%), then the consistency in the respondent's questionnaire are considered to be acceptable; otherwise, the questionnaire has to be returned for re-answering or, if this is not feasible, resolved by other means such as algorithmic method for dealing with inconsistencies in pairwise comparisons, which improves the reliability of the results. The aim of this chapter is to present the method that can be used to solve inconsistencies in pairwise comparisons. The method was introduced by Gonzalez and Romero (2003). The paper proposed Goal Programming as an attractive and flexible tool for a distance-based framework for analysing this kind of compatibility.

It had been suggested by Gonzalez and Romero (2003) that the pairwise comparison (PC) method is a powerful inference tool that permits to build a global rank from local ones by using metrical algebra. The main objective of the PC method is to assign a set of numerical weights (W_1,..,W_n) to *n* items, reflecting the recorded information contained in the PC matrix. That is because reciprocity and consistency of the PC matrix are expected. Some of the well-known methods based upon PCs, like AHP, adopt a behaviourist perspective, intransitivity and/or cycles have been allowed. In mathematics, intransitivity (sometimes called nontransitivity) is a property of binary relations that are not transitive relations. This may include any relation that is not transitive, or the stronger property of anti-transitivity, which describes a relation that is never transitive. The term intransitivity is often used when speaking of scenarios in which a relation describes the relative preferences between pairs of options, and weighing several options produces a "loop" of preference. Therefore such a preference loop (or "cycle") is known as an intransitivity

(Schmidt, 2010). In fact, these kind of methods control DM's judgments only by using a recommended value for a consistency ratio. However, if the PC matrix contains ordinal intransitivity, or cycles, then the probability of surpassing the recommended consistency ratio (e.g. 0.10 in the AHP method) is very high.

5.1 Method For Improving Consistency

Gonzalez and Romero (2003) discuss the following general problem: how to modify, with at least changes as possible, the information contained in the inconsistent PC matrix (see equation 5.1) in order to approximate it, as close as possible, to a reciprocal and consistent modified matrix, as now reciprocal matrices are complex to analyzse in practice. For solving this problem, Goal Programming was proposed as an appropriate tool. The goal programming model formulation for a sample matrix of size four is presented in model (5.2-5.6). The model presented has also been modified from Gonzalez and Romero's model in order to force the resulting weight matrix to maintain reciprocity. Goal set (5.3) aims to achieve the similarity condition compared to the original matrix. (5.4) is therefore an set of equality constraints rather than goals to ensure reciprocity. (5.5) aims to improve consistency of the matrix. And (5.6) ensures the range is kept within the AHP scale.

$$M = \begin{bmatrix} 1.00 & 5.00 & 0.50 & 3.00 \\ 0.20 & 1.00 & 3.00 & 0.33 \\ 2.00 & 0.33 & 1.00 & 0.50 \\ 0.33 & 3.00 & 2.00 & 1.00 \end{bmatrix} \tag{5.1}$$

Achievement function:

$$\text{MIN a} = \text{u} \sum_{i=1}^{12} \left(n_i^{(1)} + p_i^{(1)} \right) + \sum_{t=1}^{24} \left(n_t^{(3)} + p_t^{(3)} \right) \tag{5.2}$$

Subject to:

$$w_{12} - 5.00 + n_1^{(1)} - p_1^{(1)} = 0, \quad w_{13} - 0.50 + n_2^{(1)} - p_2^{(1)} = 0, \quad w_{14} - 3.00 + n_3^{(1)} - p_3^{(1)} = 0, \tag{5.3}$$

$$w_{21} - 0.20 + n_4^{(1)} - p_4^{(1)} = 0, \quad w_{23} - 3.00 + n_5^{(1)} - p_5^{(1)} = 0, \quad w_{24} - 0.33 + n_6^{(1)} - p_6^{(1)} = 0,$$

$$w_{31} - 2.00 + n_7^{(1)} - p_7^{(1)} = 0, \quad w_{32} - 0.33 + n_8^{(1)} - p_8^{(1)} = 0, \quad w_{34} - 0.50 + n_9^{(1)} - p_9^{(1)} = 0,$$

$$w_{41} - 0.33 + n_{10}^{(1)} - p_{10}^{(1)} = 0, \quad w_{42} - 3.00 + n_{11}^{(1)} - p_{11}^{(1)} = 0, \quad w_{43} - 2.00 + n_{12}^{(1)} - p_{12}^{(1)} = 0;$$

$$w_{12}w_{21} = 1, \quad w_{13}w_{31} = 1, \quad w_{14}w_{41} = 1, \tag{5.4}$$

$$w_{23}w_{32} = 1, \quad w_{24}w_{42} = 1, \quad w_{34}w_{43} = 1;$$

$$w_{13}w_{32} - w_{12} + n_1^{(3)} - p_1^{(3)} = 0, \quad w_{13}w_{32} - w_{12} + n_1^{(3)} - p_1^{(3)} = 0, \tag{5.5}$$

$$w_{12}w_{23} - w_{13} + n_3^{(3)} - p_3^{(3)} = 0, \quad w_{14}w_{43} - w_{13} + n_4^{(3)} - p_4^{(3)} = 0,$$

$$w_{12}w_{24} - w_{14} + n_5^{(3)} - p_5^{(3)} = 0, \quad w_{13}w_{34} - w_{14} + n_6^{(3)} - p_6^{(3)} = 0,$$

$$w_{23}w_{31} - w_{21} + n_7^{(3)} - p_7^{(3)} = 0, \quad w_{24}w_{41} - w_{21} + n_8^{(3)} - p_8^{(3)} = 0,$$

$$w_{21}w_{13} - w_{23} + n_9^{(3)} - p_9^{(3)} = 0, \quad w_{24}w_{43} - w_{23} + n_{10}^{(3)} - p_{10}^{(3)} = 0,$$

$$w_{21}w_{14} - w_{24} + n_{11}^{(3)} - p_{11}^{(3)} = 0, \quad w_{23}w_{34} - w_{24} + n_{12}^{(3)} - p_{12}^{(3)} = 0,$$

$$w_{32}w_{21} - w_{31} + n_{13}^{(3)} - p_{13}^{(3)} = 0, \quad w_{34}w_{41} - w_{31} + n_{14}^{(3)} - p_{14}^{(3)} = 0,$$

$$w_{31}w_{12} - w_{32} + n_{15}^{(3)} - p_{15}^{(3)} = 0, \quad w_{34}w_{42} - w_{32} + n_{16}^{(3)} - p_{16}^{(3)} = 0,$$

$$w_{31}w_{14} - w_{34} + n_{17}^{(3)} - p_{17}^{(3)} = 0, \quad w_{32}w_{24} - w_{34} + n_{18}^{(3)} - p_{18}^{(3)} = 0,$$

$$w_{42}w_{21} - w_{41} + n_{19}^{(3)} - p_{19}^{(3)} = 0, \quad w_{43}w_{31} - w_{41} + n_{20}^{(3)} - p_{20}^{(3)} = 0,$$

$$w_{41}w_{12} - w_{42} + n_{21}^{(3)} - p_{21}^{(3)} = 0, \quad w_{43}w_{32} - w_{42} + n_{22}^{(3)} - p_{22}^{(3)} = 0,$$

$$w_{41}w_{13} - w_{43} + n_{23}^{(3)} - p_{23}^{(3)} = 0, \quad w_{42}w_{23} - w_{43} + n_{24}^{(3)} - p_{24}^{(3)} = 0;$$

$$0.11 \le w_{ij} \le 9; \tag{5.6}$$

According to the mentioned GP achievement function, u is a weight used to multiply to the models in LINGO for sensitivity analysis (see experimental section). Computer software LINGO version 14.0 and Microsoft Excel 2010 edition are used as analytical tools for model solution and data analysis respectively. The results will be shown by highlighting three out of the eight companies. (the rest can be seen in appendix C).

5.2 Experiments

This section will be discussed regarding the data from the previous chapter being modified by LINGO software. Chen et al. (2013) states that criteria weights determined from pairwise comparisons are often the greatest contributor to the uncertainties in the AHP-based multi-criteria decision making (MCDM). During an MCDM process, the weights can be changed directly by adjusting the output from a pairwise comparison matrix, or indirectly by recalculating the matrix after varying its input. Corresponding weight sensitivity on multi-criteria evaluation results is generally difficult to be quantitatively assessed. Therefore, the models used of each of companies will be multiplied by weights u (from u = 1 to u = 10) in equation (5.2) in order to obtain the weight sensitivity analysis. This analysis provides us reliability when we come to the selection of the modified results.

5.2.1 Supplier Selection Analysis (Shinawatra Thai silk)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.12	0.13	0	0
1	0	0	0.33	4
2	0	0	0.33	4
3	0	0	0.33	4
4	0	0	0.33	4
5	0	0	0.33	4
6	0	0	0.33	4
7	0	0	0.33	4
8	0	0	0.33	4
9	0	0	0.33	4
10	0	0	0.33	4

Table 5.1: Weights Sensitivity Analysis of Supplier Selection of Shinawatra
Source: Organised by author

Table 5.1 represents the C.I, C.R., A.C, and M.C results of Shinawatra Thai silk's Supplier Selection which were analysed by using LINGO. C.I and C.R. results are all less than 0.1. A.C. and M.C values are all the same from 1 to 10. In this case, all modified PCs are all reliable and ready to use for further analysis.

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	1	4	4	0.37
Service Level	1	1	5	5	0.42
Management	0.25	0.2	1	5	0.15
Financial Flow	0.25	0.2	0.2	1	0.06

1				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

2				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

3				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

4				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

5				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

6				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

7				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

8				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

9				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

10				Weights
1	0.8	4	4	0.36
1.25	1	5	5	0.45
0.25	0.2	1	1	0.09
0.25	0.2	1	1	0.09

Table 5.2: Modified data of Supplier Selection of Shinawatra Thai silk

Source: Organised by author

Table 5.2 represents the results of Shinawatra Thai silk's supplier selection. It is discovered in the previous chapter that "Service Level" was the first priority of the company. The modified matrices provide almost identical that "Service Level" is still the first. C.I and C.R. were less than 0.1 (see in Table 5.1) then the consistency in the respondent's questionnaire was now considered to be acceptable.

5.2.2 Decision in Inventory Management Analysis (Shinawatra Thai silk)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.24	0.22	0	0
1	0	0	0.74	8.8
2	0	0	0.71	7.5
3	0	0	0.67	6.2
4	0	0	0.64	5.3
5	0	0	0.63	4.6
6	0.03	0.027	0.38	4.3
7	0.05	0.045	0.34	4.3
8	0.07	0.063	0.26	3.2
9	0.07	0.063	0.25	3
10	0.07	0.063	0.25	3

Table 5.3: Weights Sensitivity Analysis of Decision in Inventory Management of Shinawatra

Source: Organised by author

Table 5.3 represents the C.I, C.R., A.C, and M.C results of Shinawatra Thai silk's Decision in Inventory Management which were analysed by using LINGO. C.I and C.R. results are less than 0.1. Considering the weights 1-5, the models manage to take C.I and C.R down to 0. However, the values are slightly increased from 6-10. The reason is that 6-10 models achieve less A.C and M.C compared to 1-5. There is therefore a trade-off between those values in order to maintain similarity to the original matrix. There are differences among the M.C results. The less in M.C, the more reliability we are provided. In this case, C.I and C.R. at 9 and 10 are the most reliable.

Decision Variables	Original Rating					Weights
	I.C.	I.S.	B.C.	D.T.	T.R.	
Inventory Cost	1	4	1	0.33	0.25	0.17
Inventory Space	0.25	1	1	1	0.33	0.11
Budget Constraint	1	1	1	3	1	0.23
Delivery Time	3	1	0.33	1	1	0.20
Turnover rate	4	3	1	1	1	0.29

1					Weights
1	0.41	0.41	0.33	0.25	0.08
2.45	1	1	0.82	0.61	0.19
2.45	1	1	0.82	0.61	0.19
3.00	1.23	1.23	1	0.75	0.23
4	1.63	1.63	1.33	1	0.31

6					Weights
1	0.75	0.75	0.33	0.25	0.10
1.33	1	1	1	0.333	0.16
1.33	1	1	1	0.75	0.19
3.00	1	1	1	0.75	0.22
4	3.0	1.33	1.33	1	0.34

2					Weights
1	0.471	0.47	0.33	0.25	0.08
2.12	1	1	0.71	0.53	0.17
2.12	1	1	0.71	0.53	0.17
3.00	1.41	1.41	1	0.75	0.25
4	1.89	1.89	1.33	1	0.33

7					Weights
1	0.75	0.75	0.333	0.25	0.10
1.33	1	1	1	0.333	0.16
1.33	1	1	1.23	0.927	0.20
3.0	1	0.81	1	0.75	0.21
4	3.003	1.08	1.33	1	0.33

3					Weights
1	0.56	0.48	0.33	0.25	0.08
1.80	1	0.87	0.6	0.45	0.15
2.08	1.15	1	0.69	0.52	0.17
3.00	1.67	1.45	1	0.75	0.25
4	2.22	1.93	1.33	1	0.34

8					Weights
1	0.947	0.947	0.333	0.25	0.12
1.06	1	1	1	0.333	0.15
1.06	1	1	1.333	1	0.21
3.0	1	0.750	1	0.75	0.21
4	3.003	1	1.33	1	0.32

4					Weights
1	0.639	0.49	0.33	0.25	0.09
1.56	1	0.76	0.52	0.39	0.13
2.05	1.31	1	0.68	0.51	0.18
3.00	1.92	1.46	1	0.75	0.26
4	2.6	1.95	1.33	1	0.34

9					Weights
1	1	1	0.333	0.25	0.12
1	1	1	1	0.333	0.15
1	1	1	1.33	1	0.20
3.00	1	0.750	1	0.75	0.21
4	3.003	1	1.33	1	0.32

5					Weights
1	0.72	0.50	0.33	0.25	0.05
1.39	1	0.69	0.46	0.35	0.07
2.02	1.45	1	0.67	0.50	0.10
3.00	2.16	1.49	1	0.75	0.15
4	2.87	1.99	1.33	1	0.20

10					Weights
1	1	1	0.333	0.25	0.12
1	1	1	1	0.333	0.15
1	1	1	1.33	1	0.20
3.00	1	0.750	1	0.75	0.21
4	3.003	1	1.33	1	0.32

Table 5.4: Modified data of Decision in Inventory Management of Shinawatra

Source: Organised by author

Table 5.4 represents the results of Shinawatra Thai silk's Decision in Inventory Management. It was discovered in the previous chapter that "Turnover Rate" is the first priority of the company. The most reliable modified one (9 and 10) provide us identical rating that "Turnover Rate" is still the first. C.I and C.R. were less than 0.1 (see in Table 5.3) then the consistency in the respondent's questionnaire was now considered to be acceptable.

5.2.3 Supplier Selection Analysis (Classic Model co. ltd)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.44	0.49	0	0
1	0	0	1.67	8.0
2	0	0	1.11	8.0
3	0	0	1.67	8.0
4	0	0	1.67	8.0
5	0	0	1.11	8.0
6	0	0	1.11	8.0
7	0	0	1.67	8.0
8	0	0	1.11	8.0
9	0	0	1.11	8.0
10	0	0	1.11	8.0

Table 5.5: Weights Sensitivity Analysis of Supplier Selection of Classic Model,
Source: Organised by author

Table 5.5 represents the C.I, C.R., A.C, and M.C results of Classic Model co. ltd's Supplier Selection. C.I and C.R. results are less than 0.1. M.C values are all the same from 1 to 10. However, there are difference among A.C. results. In this case, the minimal A.C. values are 1.11 which can be more reliable.

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	0.11	9	9	0.23
Service Level	9	1	9	9	0.68
Management	0.11	0.11	1	0.11	0.03
Financial Flow	0.11	0.11	9	1	0.08

1				Weights
1	0.11	1	1	0.08
9.0	1	9	9	0.75
1	0.11	1	1	0.08
1	0.11	1	1	0.08

6				Weights
1	1	9	9	0.36
1	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

2				Weights
1	1	9	9	0.36
1	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

7				Weights
1	0.11	1	1	0.07
9.0	1	9	9	0.60
1	0.11	1	1	0.07
1	0.11	1	1	0.07

3				Weights
1	0.11	1	1	0.07
9.0	1	9	9	0.60
1	0.11	1	1	0.07
1	0.11	1	1	0.07

8				Weights
1	1	9	9	0.36
1	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

4				Weights
1	0.11	1	1	0.07
9.00901	1	9	9	0.60
1	0.11	1	1	0.07
1	0.11	1	1	0.07

9				Weights
1	1.00	9	9	0.36
1	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

5				Weights
1	1	9	9	0.36
1	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

10				Weights
1	1.00	9	9	0.36
1.0	1	9	9	0.36
0.11	0.11	1	1	0.04
0.11	0.11	1	1	0.04

Table 5.6: Modified data of Supplier Selection of Classic Model

Source: Organised by author

We discovered in the previous chapter that “Service Level” was only the first priority of the company when choosing for suppliers. The modified ones provide us different results that “Service Level” and “Product Quality” had become equally important. C.I and C.R. were less than 0.1 (see in Table 5.5) then the consistency in the respondent’s questionnaire was now considered to be acceptable.

5.2.4 Decision in Inventory Management Analysis (Classic Model co. ltd)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.38	0.34	0	0
1	0	0	1.14	9
2	0	0	1.14	9
3	0	0	1.14	9
4	0	0	1.14	9
5	0	0	1.14	9
6	0	0	1.14	9
7	0	0	1.14	9
8	0	0	1.14	9
9	0	0	0.91	9
10	0	0	0.89	9

Table 5.7: Weights Sensitivity Analysis of Decision in Inventory Management of Classic Model

Source: Organised by author

Table 5.7 represents the results of Classic Model co. ltd’s Decision in Inventory Management analysed by using LINGO. C.I and C.R. results are now less than 0.1. M.C values are all the same from 1 to 10. However, there are difference among A.C. results. In this case, the minimal A.C. value was 0.89 at the 10, which can be more reliable.

Decision Variables	Original Rating					Weights
	I.C.	I.S.	B.C.	D.T.	T.R.	
Inventory Cost	1	0.1	1	0.1	1	0.05
Inventory Space	9	1	9	0.1	1	0.21
Budget Constraint	1	0.1	1	0.1	1	0.05
Delivery Time	9	9	9	1	1	0.54
Turnover rate	1	1	1	1	1	0.15

1					Weights
1	0.41	0.41	0.33	0.25	0.08
2.45	1	1	0.82	0.612	0.08
2.45	1	1	0.82	0.612	0.08
3.00	1.2	1.23	1	0.75	0.68
4	1.6	1.63	1.33	1	0.09

6					Weights
1	0.75	0.75	0.33	0.25	0.07
1.33	1	1	1	0.33	0.07
1.33	1	1	1	0.75	0.07
3.00	1	1	1	0.75	0.67
4	3.00	1.33	1.33	1	0.10

2					Weights
1	0.471	0.471	0.33	0.25	0.07
2.12	1	1	0.71	0.53	0.07
2.12	1	1	0.71	0.53	0.07
3.00	1.41	1.41	1	0.75	0.68
4	1.89	1.89	1.33	1	0.10

7					Weights
1	0.75	0.75	0.333	0.25	0.07
1.33	1	1	1	0.33	0.07
1.33	1	1	1.23	0.93	0.07
3.00	1	0.81	1	0.75	0.67
4	3.003	1.08	1.33	1	0.10

3					Weights
1	0.56	0.48	0.33	0.25	0.07
1.80	1	0.87	0.6	0.45	0.07
2.08	1.15	1	0.69	0.52	0.07
3.00	1.67	1.45	1	0.75	0.67
4	2.22	1.93	1.33	1	0.10

8					Weights
1	0.95	0.95	0.333	0.25	0.07
1.06	1	1	1	0.33	0.07
1.06	1	1	1.33	1	0.07
3.00	1	0.750	1	0.75	0.67
4	3.003	1	1.33	1	0.11

4					Weights
1	0.64	0.487	0.33	0.25	0.07
1.56	1	0.763	0.52	0.39	0.07
2.05	1.31	1	0.68	0.51	0.07
3.00	1.92	1.46	1	0.75	0.67
4	2.56	1.95	1.33	1	0.10

9					Weights
1	1	1	0.33	0.25	0.08
1	1	1	1	0.33	0.08
1	1	1	1.33	1	0.08
3.00	1	0.75	1	0.75	0.63
4	3.00	1	1.33	1	0.11

5					Weights
1	0.72	0.50	0.33	0.25	0.07
1.39	1	0.69	0.464	0.348	0.07
2.02	1.45	1	0.671	0.503	0.07
3.00	2.16	1.49	1	0.75	0.67
4	2.87	1.99	1.33	1	0.10

10					Weights
1	1	1	0.333	0.25	0.086
1	1	1	1	0.33	0.086
1	1	1	1.33	1	0.086
3.00	1	0.750	1	0.75	0.621
4	3.00	1	1.33	1	0.121

Table 5.8: Modified data of Decision in Inventory Management of Classic Model
Source: Organised by author

It was discovered in the previous chapter that "Delivery Time" was the first priority of the company when consider inventory management. The most reliable modified one (10) provides identical rating that "Delivery Time" is still come out on top. C.I and C.R. were less than 0.1 (see in Table 5.7) then the consistency in the respondent's questionnaire was now considered to be acceptable.

5.2.5 Supplier Selection Analysis (Paothong Thai Silk co. ltd)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.39	0.44	0	0
1	0	0	0.94	7.0
2	0	0	0.94	7.0
3	0	0	0.94	7.0
4	0	0	0.94	7.0
5	0	0	0.93	7.0
6	0	0	0.93	7.0
7	0	0	0.93	7.0
8	0	0	0.93	7.0
9	0	0	0.93	7.0
10	0	0	0.93	7.0

Table 5.9: Weights Sensitivity Analysis of Supplier Selection of Paothong

Source: Organised by author

Table 5.9 represents the results of Paothong Thai Silk co. ltd’s supplier selection analysed by using LINGO. C.I and CR. results are now less than 0.1. M.C values are all the same from 1 to 10. However, there are difference among A.C. results. In this case, the minimal A.C. values are 0.93 which can be more reliable.

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	8	9	9	0.68
Service Level	0.125	1	0.125	8	0.08
Management	0.111	8	1	8	0.22
Financial Flow	0.111	0.125	0.125	1	0.03

1				Weights
1	8	1.12	9	0.47
0.125	1	0.14	1.125	0.06
0.888	7.111	1	8	0.42
0.111111	0.888	0.125	1	0.05

6				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

2				Weights
1	8	1.125	9	0.47
0.125	1	0.14	1.125	0.06
0.888	7.111	1	8	0.42
0.111	0.888	0.125	1	0.05

7				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

3				Weights
1	8	1.125	9	0.47
0.125	1	0.14	1.125	0.06
0.888	7.111	1	8	0.42
0.111	0.888	0.125	1	0.05

8				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

4				Weights
1	8	1.125	9	0.47
0.125	1	0.14	1.125	0.06
0.888	7.111	1	8	0.42
0.111	0.888	0.125	1	0.05

9				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

5				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

10				Weights
1	8	1.125	9	0.47
0.125	1	0.125	1.125	0.06
0.888	8	1	8	0.43
0.111	0.888	0.125	1	0.05

Table 5.10: Modified data of Supplier Selection of Paothong

Source: Organised by author

From the previous chapter (the AHP analysis), it was discovered that “Product Quality” was the first priority of the company. The modified ones provide different results that “Management” had become almost equal to “Product Quality”. C.I and C.R. are now less than 0.1 (see in Table 5.9) then the consistency in the respondent’s questionnaire was now considered to be acceptable.

5.2.6 Decision in Inventory Management Analysis (Paothong Thai Silk co. ltd)

Weight (u)	C.I.	C.R.	Average Change	Maximum Change
Original	0.56	0.5	0	0
1	0	0	1.40	9
2	0	0	1.43	8
3	0	0	1.43	8
4	0	0	1.43	8
5	0	0	1.43	8
6	0	0	1.43	8
7	0	0	1.42	8
8	0	0	1.42	8
9	0	0	1.42	8
10	0	0	1.38	8

Table 5.11: Weights Sensitivity Analysis of Decision in Inventory Management of Paothong

Source: Organised by author

Table 5.11 represents the C.I, C.R., A.C, and M.C results of Paothong Thai Silk co. ltd's regarding to their decision in inventory management analysed by using LINGO. C.I and CR. are all less than 0.1. However, there are difference among A.C. and M.C results. The minimal A.C. value is 1.38. The minimal M.C. values are 8. Therefore, the 10 has become the most reliable compared to the others.

Decision Variables	Original Rating					Weights
	I.C.	I.S.	B.C.	D.T.	T.R.	
Inventory Cost	1	9	9	0.11	0.125	0.11
Inventory Space	0.11	1	9	0.125	0.125	0.05
Budget Constraint	0.111	0.11	1	0.125	0.125	0.02
Delivery Time	9	8	8	1	9	0.59
Turnover rate	8	8	8	0.11	1	0.24

1					Weights
1	0.888	1	0.111	0.125	0.05
1.125	1	1.125	0.125	0.14	0.06
1	0.888	1	0.111	0.125	0.05
9	8	9	1	1.125	0.45
8	7.111	8	0.888	1	0.40

6					Weights
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
8	8	8	1	1	0.42
8	8	8	1	1	0.42

2					Weights
1	0.999	0.999	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
8	8	8	1	1	0.42
8	8	8	1	1	0.42

7					Weights
1	1	1	0.111	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
9	8	8	1	1	0.43
8	8	8	1	1	0.42

3					Weights
1	1	0.999	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
8	8	8	1	1	0.42
8	8	8	1	1	0.42

8					Weights
1	1	1	0.111	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
9	8	8	1	1	0.43
8	8	8	1	1	0.42

4					Weights
1	1	0.999	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
8	8	8	1	1	0.42
8	8	8	1	1	0.42

9					Weights
1	1	1	0.111	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
9	8	8	1	1	0.43
8	8	8	1	1	0.42

5					Weights
1	1	0.999	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
8	8	8	1	1	0.42
8	8	8	1	1	0.42

10					Weights
1	1	1	0.111	0.125	0.05
1	1	1	0.125	0.125	0.05
1	1	1	0.125	0.125	0.05
9	8	8	1	1.125	0.44
8	8	8	0.888	1	0.41

Table 5.12: Modified data of Decision in Inventory Management of Paothong

Source: Organised by author

We discovered that "Delivery Time" was the first priority of the company considering the Chapter 4. The most reliable modified result is the 10, giving different results that "Turnover Rate" has become almost equal to "Delivery Time". C.I and C.R. are less than 0.1 (see in Table 5.11) then the consistency in the respondent's questionnaire was now considered to be acceptable.

5.3 Summary of inconsistencies in pairwise comparisons analysis

This chapter discusses how the reliability of the AHP results were obtained by using the method developed by Gonzalez and Romero (2003). This method was to use Goal Programming as a tool to solve inconsistencies in AHP pairwise comparisons. The specific GP model was presented (see equation 5.2). The computer software: LINGO version 14.0 and Microsoft Excel 2010 edition were used as analytical tools. The experiment sections then presented the PC matrix from the previous chapter being modified by using the software. The results for each of companies were multiplied by the weight (u). This is in order to compare between one another. This analysis provided a reliability when it comes to the selection of the modified rating results. The results were summarised as seen in Table 5.13.

Supplier Selection			
	Shinawatra	Classic Model	Paothong
Product Quality	0.36	0.36 ✓	0.47 ✓
Service Level	0.45 ✓	0.36 ✓	0.06
Management	0.15	0.04	0.43
Financial Flow	0.06	0.04	0.05
CR < 0.1 (10%)	0	0	0

Decision in Inventory Management			
	Shinawatra	Classic Model	Paothong
Inventory Cost	0.12	0.086	0.05
Inventory Space	0.15	0.086	0.05
Budget Constraint	0.20	0.086	0.05
Delivery Time	0.21	0.621 ✓	0.44 ✓
Turnover rate	0.32 ✓	0.121	0.41
CR	0.063	0	0.00

Table 5.13: Summary Table of the Acceptable Consistency Ratios

Source: Organised by author

5.4 Conclusion

In this chapter, we are interested on the following problem: how to modify the information contained in the AHP PC matrix obtained from the previous chapter (chapter 4). This is in order to approximate it, as closely as possible to with modified matrix. For solving the problem of inconsistency in the respondent's questionnaire, Goal Programming is proposed as an interesting tool. From the author's point of view, the respondents are familiar with the processes of their company and industry. However, they appear to be less familiar with the use of pairwise comparisons of AHP methodology, resulting in the relatively high levels of inconsistency. Therefore in order to reduce the inconsistency level, rather than retuning the questionnaire to the key decision makers for re-answering, an automated algorithm is selected instead. This is because the authors avoids to point inconsistencies out to decision makers and are not confident that a re-answering will lead to an acceptable level of inconsistency. Therefore a numerical method was chosen that searches for consistency whilst differing from the original responses ‘‘as little as possible’’. The selected method was introduced by Gonzalez and Romero (2003). The paper proposed Goal Programming as an attractive and flexible tool for a distance-based framework for analysing this kind of compatibility to solve inconsistencies in pairwise comparisons. The main idea of the proposed GP model is how to modify, with at least changes as possible, the information contained in inconsistent PC matrix in order to approximate it, as closely as possible, to a reciprocal and consistent modified matrix. The Gonzalez and Romero (2003) is modified to enforce repricocity, as non reciprocal matrices are complex to analyse in practice. According to the experiences of this experiment, the challenge was to keep the modified pairwise comparison matrix as close as possible to the original. After solving the models, the consistency values for all eight companies became less than 10 %, which means the adjusted consistency is now considered to be acceptable for further analysis. The next chapter will be discussed regarding the method of using Data Envelopment Analysis (DEA) for measuring an efficiency of existing suppliers and inventory departments of the case studies.

Chapter 6 Efficiency Analysis using Data Envelopment Analysis (DEA)

Introduction

The previous chapter (Chapter 5) provided the results that had been modified by using the method for dealing with inconsistencies in pairwise comparisons (Gonzalez and Romero, 2003), applied in the three case studies. C.I and C.R. values were less than 0.1, which means that the consistencies were now considered to be acceptable. The aim of this chapter is to present the method of using DEA (Data Envelopment Analysis), that can be used for measuring an efficiency of companies' existing suppliers and inventory departments in the case studies.

This chapter will first introduce concepts of the Thai silk manufacturers efficiency analysis. This part will be also discussed in the orientation of the model analysis, which the sets of inputs and outputs will be introduced in order to implement an analysis. The experimental section will then be presented. The results will be shown by selecting three representative companies from the eight. (the rest can be seen in appendix F).

6.1 Concepts of The Thai Silk Manufacturers Efficiency Analysis

A set of data is required to evaluate the efficiency of the 8 samples of the Thai silk manufacturers examined in this research. The data set is acquired from the statistic data of the manufacturers regarding their existing suppliers and recent sample orders kept in the inventories. The existing suppliers in each of the manufactures will be measured regarding their performances. The recent sample orders in each of manufacturers will be measured regarding their recorded inventory data to find out actual efficiency level. This analysis provides key decision makers a clear vision to find out where are the problems to pay more attention to when considering their suppliers and past inventory activities.

6.1.1 The Orientation of The DEA Analysis

Once concepts of DEA analysis has been made, an orientation of the model to determine the measurement of the efficiency is needed. There are two basic orientations, which include both inputs and outputs. An input orientation focuses on the proportional decrease of the input vector while the output orientation adjusts the proportional increase of the output (Martin and Roman 2001). The samples involved in this research determine the selection of the orientation. An output orientation is employed in this research because once manufacturers have invested in something such as the building of inventory space or purchasing of vehicles , it is difficult for manufacturers authorities to disinvest to save costs by amending their input variables to invalidate the input orientation. The selected inputs and outputs for data analysis can be seen in Table 6.1 and Table 6.2.

Inputs	Outputs
Average Cost per Unit	Product Quality
Labours	Service Level
Vehicles	Management
	Financial Flow

Table 6.1: Inputs and Outputs for Suppliers analysis

Source: Organised by author

Table 6.1 represents the sets of inputs and outputs for suppliers' efficiency analysis. Supplier selection is a key task for firms, enabling them to achieve the objectives of a supply chain. Selecting a supplier is based on multiple conflicting factors, such as quality and cost, which are represented by a multi-criteria description of the problem (Guneri, 2011). According to an interview with the pilot interviews in Thailand regarding supplier selection perspectives (see in Chapter 4), there are three inputs that are commonly considered for an investment. The inputs consist of average cost per unit, labour (a number of people used for dealing with specific supplier), and vehicles (a number of vehicles used for transportation). The considered outputs are the same as presented and detailed in AHP analysis (see Table 4.1) as: product quality, service level, management, and financial flow. In order to generate numerical data for the outputs, a 1-5 rating scales method is undertaken. Combining words and numbers in a 1-to-5 rating scale provides an effective yet simple method for measuring the relative performance or importance of personal and business options. Therefore, in terms of suppliers' performance analysis, the decision makers are required to rate those outputs by using 1-5 rating scales.

Inputs	Outputs
SKUs (Stock Keeping Units)	**Inventory Cost** (Total Inventory cost of the order)
Inventory Space (Squre Metre for stocking)	**Delivery Time** (On time percentage Rating)
Budget (Annual Budet per order per year)	**Turnover Rate** (Annual Turnover)
Labours	

Table 6.2: Inputs and Outputs for inventory management analysis
Source: Organised by author

Table 6.2 represents the sets of inputs and outputs for inventory efficiency analysis. According to an interview with the experts in Thailand regarding their inventory management, there are four commonly considered for an investment. The inputs consist of stock keeping units, space, budget, and labour. The outputs are as follows; inventory cost, delivery time, and turnover. Regarding "Inventory Cost", manufacturers in the industry have been working hard in order to reduce it to a low level. In order to use the standard DEA form, all "Inventory Cost" data in the experimental sections will be changed into maximization "more is better" format by a simple mathematical transformation.

6.2 Experiments

This section will be discussed regarding efficiency analysis of suppliers and inventories of the manufacturers case studies. The selected computer software for analysis was LINGO version 14.0. A performance ratio is calculated by the presence of multiple input and output factors defined as:

$$Efficiency = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs}$$

6.2.1 Efficiency Analysis of Shinawatra Thai silk

6.2.1.1 Suppliers' Efficiency Analysis

According to the information provided from Shinawatra Thai silk, there were five of the existing suppliers that the manufacturer provided information for an analysis. The list of suppliers were as: Supplier-1, Supplier-2, Supplier-3, Supplier-4, and Supplier-5. The list of the suppliers are set as: Supplier No.1-5 for reasons of confidentiality. The sets of inputs and outputs for each of the suppliers are given as seen in Table 6.3.

Shinawatra Thai Silk	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	1300	8	5		4	3	3	4
Supplier-2	1400	10	7		4	3	3	2
Supplier-3	1050	8	8		4	3	2	4
Supplier-4	950	5	3		4	5	4	5
Supplier-5	1200	7	5		4	2	4	3

Table 6.3: DEA inputs and outputs data from Shinawatra Thai silk

Source: Organised by author

6.2.1.2 DEA Scores

Shinawatra Thai Silk	DEA Scores
Suppliers	
Supplier-1	**0.73**
Supplier-2	**0.67**
Supplier-3	**0.9**
Supplier-4	**1**
Supplier-5	**0.79**

Table 6.4: DEA Scores from Supplier Analysis of Shinawatra Thai silk

Source: Organised by author

Table 6.4 represents the results of Shinawatra Thai silk's DEA analysis regarding their existing suppliers. Considering the results, "Supplier-4" got 100 percent which was the best supplier among the rest. The minimal score received was "Supplier-2" (67 percent). The manufacturer might make a decision how to work with those inefficient ones when considering to supplier selection.

6.2.1.3 Inventory Efficiency Analysis of Shinawatra Thai silk

According to the information provided from Shinawatra Thai silk, there were five recent orders that the manufacturer provided us for an analysis. The sample orders consists Convertible neck, Boat neck-1, Mandarin neck, Shawl neck, and Round neck-1. The sets of inputs and outputs for each of the orders are given in Table 6.5.

Shinawatra Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Convertible neck	784	10	980000	10		10092	100	0.51
Sample Order 2	Boat neck-1	392	5	490000	7		14796	100	0.71
Sample Order 3	Mandarin neck	784	9	980000	7		10092	100	0.65
Sample Order 4	Shawl neck	784	10	980000	7		10092	100	0.77
Sample Order 5	Round neck-1	1176	15	1470000	15		5388	100	0.82

Table 6.5: DEA inputs and outputs data from Shinawatra Thai silk

Source: Organised by author

6.2.1.4 DEA Scores

Shinawatra Thai Silk		DEA Scores
Sample Order 1	Convertible neck	**0.7**
Sample Order 2	Boat neck-1	**1**
Sample Order 3	Mandarin neck	**1**
Sample Order 4	Shawl neck	**1**
Sample Order 5	Round neck-1	**0.52**

Table 6.6: DEA Scores from Inventory Analysis of Shinawatra Thai silk

Source: Organised by author

Table 6.6 represents the results of Shinawatra Thai silk's DEA analysis regarding the recent sample orders. Considering the results, Convertible neck got 70 percent and the Round neck got 52 percent, which mean two out of five are less efficient than the others. The manufacturer might focus their attention on improving these inefficient categories.

6.2.2 Efficiency Analysis of Classic Model co. ltd

6.2.2.1 Suppliers' Efficiency Analysis

According to the information from Classic Model co. ltd, there were four of the existing suppliers that the manufacturer provided their information for an analysis. The list of the suppliers are set as: Supplier No.1-4 for reasons of confidentiality. The sets of inputs and outputs for each of the suppliers are given in Table 6.7.

Classic Model	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	3200	4	3		5	5	4	4
Supplier-2	3500	5	3		5	5	4	4
Supplier-3	3000	2	2		5	5	5	5
Supplier-4	4000	5	3		4	4	5	4

Table 6.7: DEA inputs and outputs data from Classic Model co. ltd.

Source: Organised by author

6.2.2.2 DEA Scores

Classic Model	DEA Scores
Suppliers	
Supplier-1	**0.94**
Supplier-2	**0.86**
Supplier-3	**1.00**
Supplier-4	**0.75**

Table 6.8: DEA Scores from Supplier Analysis of Classic Model co. ltd.

Source: Organised by author

Table 6.8 represents the results of Classic Model co. ltd.'s DEA analysis regarding their existing suppliers. Considering the results, "Supplier-3" got 100 percent which is the best supplier among the rest. The minimal score received is "Supplier-4" (75 percent). The key decision maker may settle on a choice how work with those inefficient ones in the future.

6.2.2.3 Inventory Efficiency Analysis of Classic Model co. ltd

According to the information from Classic Model co. ltd, there were five recent orders that the manufacturer provided for an analysis. The sample orders consists Convertible neck-1, Peter neck-1, Round neck-1, Shirt neck-1, and Boat neck-1. The sets of inputs and outputs for each of the orders are given in Table 6.9.

Classic Model		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Convertible neck-1	420	8	336000	5		11627	70	0.89
Sample Order 2	Peter neck-1	560	8	448000	10		10780	80	0.78
Sample Order 3	Round neck-1	840	12	672000	10		8253	100	0.74
Sample Order 4	Shirt neck-1	420	8	336000	5		11627	90	0.80
Sample Order 5	Boat neck-1	560	8	448000	10		10780	100	0.94

Table 6.9: DEA inputs and outputs data from Classic Model co. ltd.

Source: Organised by author

6.2.2.4 DEA Scores

Classic Model		DEA Scores
Sample Order 1	Convertible neck-1	**1**
Sample Order 2	Peter neck-1	**0.93**
Sample Order 3	Round neck-1	**0.71**
Sample Order 4	Shirt neck-1	**1**
Sample Order 5	Boat neck-1	**1**

Table 6.10: DEA Scores from Inventory Analysis of Classic Model co. ltd.

Source: Organised by author

Table 6.10 represents the results of Classic Model co. ltd.'s DEA analysis regarding the recent sample orders. Considering the results, "Peter neck-1" got 0.93 percent and the "Round neck-1" got 71 percent, and the rest got 100 percent. The manufacturer may give careful consideration to those inefficient categories.

6.2.3 Efficiency Analysis of Paothong Thai Silk co. ltd

6.2.2.1 Suppliers' Efficiency Analysis

According to the information from Paothong Thai Silk co. ltd, there were four of the existing suppliers that the manufacturer provided information for an analysis. The list of the suppliers are set as: Supplier No.1-4 for reasons of confidentiality. The sets of inputs and outputs for each of the suppliers were given in Table 6.11.

Paothong Thai Silk	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	1200	7	4		4	3	2	3
Supplier-2	1300	4	2		5	4	3	4
Supplier-3	1100	4	3		5	4	3	4
Supplier-4	1300	8	4		4	3	3	2

Table 6.11: DEA inputs and outputs data from Paothong Thai Silk co. ltd.
Source: Organised by author

6.2.2.2 DEA Scores

Paothong Thai Silk Suppliers	DEA Scores
Supplier-1	**0.73**
Supplier-2	**1.00**
Supplier-3	**1.00**
Supplier-4	**0.84**

Table 6.12: DEA Scores from Supplier Analysis of Paothong Thai Silk co. ltd.
Source: Organised by author

Table 6.12 represents the results of Paothong Thai Silk co. ltd.'s DEA analysis regarding their existing suppliers. Considering the results, "Supplier-2 and Supplier-3" got 100 percent which are the best suppliers among the rest. The minimal score received is "Supplier-1" (73 percent). The manufacture may settle on a decision how to work with those inefficient ones later on.

6.2.2.3 Inventory Efficiency Analysis of Paothong Thai Silk co. ltd

According to the information from Paothong Thai Silk co. ltd, there were ten recent orders that the manufacturer provided for an analysis. The sets of inputs and outputs for each of the orders are given in Table 6.13.

Paothong Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Shirt neck-1	280	5	354667	8		6640	90	0.85
Sample Order 2	Boat neck-1	840	8	1064000	10		6587	100	0.77
Sample Order 3	Mandarin neck-1	560	7	709333	10		8280	80	0.85
Sample Order 4	Round neck-1	560	7	709333	10		8280	100	0.90
Sample Order 5	Peter neck-1	840	10	1064000	10		6587	80	0.75
Sample Order 6	Boat neck-2	560	7	709333	8		8280	100	0.92
Sample Order 7	Peter neck-2	560	7	709333	8		8280	85	0.78
Sample Order 8	Mandarin neck-2	560	8	709333	8		8280	90	0.63
Sample Order 9	Round neck-2	560	7	709333	8		8280	100	0.73
Sample Order 10	Shirt neck-2	280	5	354667	8		6640	80	0.79

Table 6.13: DEA inputs and outputs data from Paothong Thai Silk co. ltd.

Source: Organised by author

6.2.2.4 DEA Scores

Paothong Thai Silk		DEA Scores
Sample Order 1	Shirt neck-1	**1**
Sample Order 2	Boat neck-1	**0.82**
Sample Order 3	Mandarin neck-1	**0.93**
Sample Order 4	Round neck-1	**0.93**
Sample Order 5	Peter neck-1	**0.65**
Sample Order 6	Boat neck-2	**1**
Sample Order 7	Peter neck-2	**1**
Sample Order 8	Mandarin neck-2	**1**
Sample Order 9	Round neck-2	**1**
Sample Order 10	Shirt neck-2	**1**

Table 6.14: DEA Scores from Inventory Analysis of Paothong Thai Silk co. ltd.

Source: Organised by author

Table 6.14 represents the results of Paothong Thai Silk co. ltd.'s DEA analysis regarding the recent sample orders. The results shown that "Peter neck-1" got 65 percent which are considered to be the most inefficient one compared to the others. The manufacturer may give cautious thought to the inefficient one in the future.

6.3 Summary of Data Envelopment Analysis

This chapter discussed how DEA scores (see table 6.15) of manufacturers' existing suppliers and inventories were obtained by using ratios of inputs and outputs. The concept of efficiency analysis is introduced. This part also discussed the orientation of the DEA analysis, where the sets of inputs and outputs were identified for implementing an analysis. The experimental sections are then presented by the representative case studies. The data needed for an analysis was acquired from 1-5 rating scales and statistical data of the manufacturers regarding their existing suppliers and recent sample orders kept in the inventories. The recent sample orders in each of the manufacturers were measured regarding their recorded inventory data to find out the actual efficiency level.

Suppliers' Efficiency Analysis			Inventories' Efficiency Analysis	
	Suppliers	DEA Scores	Sample Orders	DEA Scores
Shinawatra	Supplier-1	0.73	Convertible neck	0.7
	Supplier-2	0.67	Boat neck-1	1
	Supplier-3	0.9	Mandarin neck	1
	Supplier-4	1	Shawl neck	1
	Supplier-5	0.79	Round neck-1	0.52
Classic Model	Supplier-1	0.94	Convertible neck-1	1
	Supplier-2	0.86	Peter neck-1	0.93
	Supplier-3	1.00	Round neck-1	0.71
	Supplier-4	0.75	Shirt neck-1	1
			Boat neck-1	1
Paothong	Supplier-1	0.73	Shirt neck-1	1
	Supplier-2	1.00	Boat neck-1	0.82
	Supplier-3	1.00	Mandarin neck-1	0.93
	Supplier-4	0.84	Round neck-1	0.93
			Peter neck-1	0.65
			Boat neck-2	1
			Peter neck-2	1
			Mandarin neck-2	1
			Round neck-2	1
			Shirt neck-2	1

Table 6.15: Summary Table of the DEA Analysis

Source: Organised by author

6.4 Conclusion

In this chapter, the manufacturers provided the information regarding their existing suppliers and recent sample orders kept in their inventories. The existing list of suppliers and recent sample orders were analysed using DEA in order to find out their performances. The DEA analysis provides key decision makers a clear vision to find out where are the problems to pay more attention when selecting their suppliers and considering the past inventory activities for better decision making in the future.

According to the experiences of this experiment, the efficiency scores of suppliers and inventories have been revealed that there are inefficient aspects of the supply chain to be considered. Song (2013) pointed out that there are many sources of uncertainties in a supply chain. The three most important categories of uncertainties are as follows: 1) supply uncertainty such as material supply or subcontract order, 2) manufacturing uncertainty such as processing time and resource availability, and 3) customer uncertainty such as customer orders or demand arrivals. In terms of those mentioned uncertainties, the first category is an external uncertainty, which occurs during raw material supply or outsourcing. The common measurement is suppliers' on-time delivery, average lateness, and degree of inconsistency. The second category is an internal uncertainty, which may be caused by set-up times, machining times, transfer times, machine failures and repairs, routine maintenance, human errors, and absenteeism, and other events inside the manufacturer. The third category is an external uncertainty, which is caused by unpredictable market environments and customer requirement changes (Song, 2013).

In terms of the scope of our research, we discover that there are supplier performance issues of the research. However those issue considered to be an external uncertainty, which is out of the scope. The manufacturers must take their own consideration whether or not they should keep running business with those less well performing suppliers. Therefore, in terms of an optimisation, the research will principally engage with inventory management, which will be discussed in the next chapter. The next chapter will discuss the method of using Goal Programming (GP) models. Since manufacturers have multiple choices to solve their existing problems, GP models will be undertaken for optimising planning

Chapter 7 Finding of Optimal Solutions using Goal-Programming (GP)

Introduction

The previous chapter (Chapter 6) presented the results of the DEA method using the ratios of inputs and outputs provided by the manufacturers for efficiency measurement. The analysis provided key decision makers a clear vision to know the actual effectiveness in each of the main areas of suppliers selection and inventory management. The aim of this chapter is then to present the method of using GP (Goal Programming) models, which can be used for optimising planning decisions in the presence of multiple conflicting objectives, giving key decision makers better actions to achieve their targets. To optimise in the context of decision making means to find the decision which gives the best possible value of some measures from amongst the set of possible decisions (Jones and Tamiz, 2010). This chapter will first introduce concepts of GP analysis. This part discusses the orientation of the models' analysis, which that objectives and goals will be introduced here in order to implement an analysis. The next will then present the experimental sections. The results will be shown by selecting three out of eight case studies (the rest can be seen in appendix H).

7.1 Concepts of GP models Analysis

There are three main GP variants: Lexicographic goal programming, Weighted goal programming, and Chebyshev goal programming. Lexicographic variant is not used for the analysis. The distinguishing feature of lexicographic goal programming is the existence of a number of priority levels (Jones and Tamiz, 2010). In this research, priority levels are not involved for the analysis. There will be three GP models used for an analysis in the research. Weighted and Chebyshev variants are undertaken. The other model will be the Extended goal programming, which is a mix between the weighted and Chebyshev. The Extended GP will be able to provide alternative solutions as an option for key decision makers. This chapter specifically focuses on an analysis of inventory optimisation. In term of this optimisation, the goals used in the GP models will be set the

same as decision variables seen in the AHP analysis chapters, which consisted of inventory cost, inventory space, budget, delivery time, and turnover. The useable AHP values can be seen in Table 5.13 (summary table of acceptable consistency ratios).
The analysis is composed of the following activities:

A. Identify the objective (e.g., the objective is to optimise all given variables in an inventory analysis).

B. From the objective in (A), determine specific goals to be achieved.

C. Use AHP result (see table 5.13) to determine the weights for the goals identified in (B).

D. Using the information in (C), develop a Weighted, Chebyshev, and Extended model and solve them to obtain optimal solutions for key decision makers.

7.1.1 The Orientation of The GP Analysis.

Once the choice of GP analysis has been made, an orientation of the model to implement the models' analysis is needed. There are four basic orientations, which include specific goals to be achieved and set of actions to achieve the goals (see table 7.1), contribution sets between actions and goals, and difficulty level required to implement those actions.

Actions	Goals
Work with suppliers to improve communications in the supply chain.	minimise inventory cost for one order to..............
Negotiate lower lead times with suppliers.	minimise space used for one order to....................
Reduce the number of part numbers carried.	minimise budget for one order in inventory to.......
Take credit and track your efforts to reduce inventory.	maximise delivery Time rate to...............................
Find ways to reduce surplus and obsolete inventory.	maximise turnover ratio to..
Improve supplier's quality to reduce costs.	
Challenge and reduce minimum order quantities.	
Improve suppliers on time delivery performance.	
Set up a supplier managed inventory programs.	

Table 7.1: Actions and Goals for GP Analysis
Source: Organised by author

Cavinato and Kauffman (2000) had presented the set of actions that can be considered when thinking of inventory improvement (see table 7.1). The author has modified the actions from the original one (see table 2.9) in order to be applicable to the analysis. The actions consist of working with suppliers to improve communications, negotiate with suppliers for lower lead times, reduce the number of spare part, take credit and track your efforts to reduce inventory, reduce surplus and obsolete inventory, improve supplier's quality to reduce costs, challenge and reduce minimum order quantities, improve suppliers on time delivery performance, and set up a supplier managed inventory programs. Table 7.1 also represents the goals that will be contributed by those actions. The goals consist of the following list:

Goal 1: is to minimise inventory cost for one order to... (determined by DM),
Goal 2: is to minimise space used for one order in inventory to… (determined by DM),
Goal 3: is to minimise budget for one order in inventory to… (determined by DM),
Goal 4: is to maximise delivery Time rate to… (determined by DM), and
Goal 5: is to maximise turnover ratio to… (determined by DM).

Actions	Goals				
	minimise inventory cost for one order (TH Baht)	minimise space used for one order in inventory (squre metre)	minimise budget for one order in inventory (TH Baht)	maximise delivery Time rate (Percentage)	maximise turnover ratio (Up to 1)
	Avg value. XXX	Avg value XXX	Avg value XXX	Avg value. XXX	Avg value. XXX
	Target	Target	Target	Target	Target
	Percentage Change	Percentage Change	Percentage Change	Percentage Change	Percentage Change
Work with suppliers to improve communications in the supply chain.					
Negotiate lower lead times with suppliers.					
Reduce the number of part numbers carried.					
Take credit and track your efforts to reduce inventory.					
Find ways to reduce surplus and obsolete inventory.					
Improve supplier's quality to reduce costs.					
Challenge and reduce minimum order quantities.					
Improve suppliers on time delivery performance.					
Set up a supplier managed inventory programs.					
45 sets of contributions in Total.					

Table 7.2: Data collection for GP Analysis

Source: Organised by author

Considering table 7.2, there are 45 sets of contributions in total (9 actions for 5 goals). Key decision makers will provide those required information in order to obtain the actual values of contribution sets (see appendix H). In order to be convenient for the interviewee to answer those conflicting questions, percentage approach was applied (e.g. how many percent do you think that Action 1 could improve Goal 1?). After that, the contribution values were generated based on the average value of each goal. The average values are the same sets of data from the DEA analysis, calculated by using the numerical information answered by the key decision makers (see Appendix A and E). The target values of the goals were also indicated according to the key decision maker's preference. After contribution values were received, decision makers will then answer how they feel in term of difficulty levels of an afford for implementing those actions (see table 7.3).

Actions		Difficulty Levels				
		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.					
X2	Negotiate lower lead times with suppliers.					
X3	Reduce the number of part numbers carried.					
X4	Take credit and track your efforts to reduce inventory.					
X5	Find ways to reduce surplus and obsolete inventory.					
X6	Improve supplier's quality to reduce costs.					
X7	Challenge and reduce minimum order quantities.					
X8	Improve suppliers on time delivery performance.					
X9	Set up a supplier managed inventory programs.					
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Table 7.3: Difficulty Levels of Actions for GP Analysis

Source: Organised by author

Table 7.3 represents the table of data collection regarding the difficulty levels of the actions that will be answered by key decision makers. There were five levels as follows; easy, normal, hard, very hard, and intense. Those levels had been given specific values as; 1, 2, 5, 8, and 10 respectively. The following sections discuss Goal Programming models' analysis of inventories of the case studies. The selected computer software for analysis was LINGO version 14.0.

7.1.2 Goal Programing Models used for Analysis

This section represents the GP models that were developed for data analysis. The models includes three variants as follows; Weighted, Extended, and Chebyshev.

7.1.2.1 Weighted GP model

$$\text{MIN a} = \sum_{k=1}^{5} \left(\frac{u_k\, n_k}{b_k} + \frac{v_k p_k}{b_k} \right) + \frac{P_d}{D}$$

Subject to

$$\sum_{i=1}^{9} e_{ik}\, x_i + n_k - p_k = b_k \qquad k = 1, \dots, 5$$

$$\sum_{i=1}^{9} d_i\, x_i + n_d - p_d = D$$

$$x_i = 0 \text{ or } 1 \qquad i = 1, \dots, 9$$

Where:

x_i is the decision variable representing whether action i is undertaken or not

p_d is the positive deviation from the target difficulty level D .

n_d is the negative deviation from the target difficulty level D .

b_k is a target value for goal *k*,

n_k is the negative deviation from (b_k)

p_k is the positive deviation from (b_k)

u_k is the negative deviation weight (from the AHP analysis).

v_k is the positive deviation weight (from the AHP analysis).

e_{ik} is the contribution of action i towards goal *k*.

d_i is the level of difficulty of implementing action i.

D is a maximum difficulty goal level for all the chosen actions.

7.1.2.2 Extended GP model

$$\text{MIN a} = a\lambda + (1-\alpha)\left[\sum_{k=1}^{5}\left(\frac{u_k\, n_k}{b_k} + \frac{v_k p_k}{b_k}\right) + \frac{P_d}{D}\right]$$

Subject to

$$\sum_{i=1}^{9} e_{ik}\, x_i \; + n_k - p_k = b_k \qquad k = 1, \ldots, 5$$

$$\sum_{i=1}^{9} d_i\, x_i \; + n_d - p_d = D$$

$$x_i = 0 \text{ or } 1 \qquad i = 1, \ldots, 9$$

$$\frac{u_k n_k}{b_k} + \frac{v_k p_k}{b_k} \leq \lambda \qquad k = 1, \ldots, 5$$

$$\frac{P_d}{D} \leq \lambda$$

Where:

x_i is the decision variable representing whether action i is undertaken or not

p_d is the positive deviation from the target difficulty level D .

n_d is the negative deviation from the target difficulty level D .

b_k is a target value for goal *k*,

n_k is the negative deviation from (b_k)

p_k is the positive deviation from (b_k)

u_k is the negative deviation weight (from the AHP analysis).

v_k is the positive deviation weight (from the AHP analysis).

e_{ik} is the contribution of action i towards goal *k.*

d_i is the level of difficulty of implementing action i.

D is a maximum difficulty goal level for all the chosen actions.

7.1.2.3 Chebyshev GP model

$$\text{MIN a} = \lambda$$

Subject to

$$\sum_{i=1}^{9} e_{ik}\, x_i + n_k - p_k = b_k \qquad k = 1, \dots, 5$$

$$\sum_{i=1}^{9} d_i\, x_i + n_d - p_d = D$$

$$x_i = 0 \text{ or } 1 \qquad i = 1, \dots, 9$$

$$\frac{u_k n_k}{b_k} + \frac{v_k p_k}{b_k} \le \lambda \qquad k = 1, \dots, 5$$

$$\frac{P_d}{D} \le \lambda$$

Where:

x_i is the decision variable representing whether action i is undertaken or not

p_d is the positive deviation from the target difficulty level D .

n_d is the negative deviation from the target difficulty level D .

b_k is a target value for goal *k*,

n_k is the negative deviation from (b_k)

p_k is the positive deviation from (b_k)

u_k is the negative deviation weight (from the AHP analysis).

v_k is the positive deviation weight (from the AHP analysis).

e_{ik} is the contribution of action i towards goal *k.*

d_i is the level of difficulty of implementing action i.

D is a maximum difficulty goal level for all the chosen actions.

7.2 The Experiments of Shinawatra Thai silk.

This section is the data collection for the GP models. Table 7.4 represents the sets of contributions answered by Shinawatra's key decision maker. Table 7.5 represents the difficulty levels to implement the actions.

Shinawatra Thai Silk	Goals									
Actions	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	9908	8000	9.8	5	1250	800	100	100	0.69	1
Work with suppliers to improve communications in the supply chain.	495.4		0.49		125		10		0.0345	
Negotiate lower lead times with suppliers.	1981.6		2.94		125		30		0.0345	
Reduce the number of part numbers carried.	1981.6		2.94		250		5		0.0345	
Take credit and track your efforts to reduce inventory.	990.8		2.94		125		5		0.138	
Find ways to reduce surplus and obsolete inventory.	495.4		2.94		250		5		0.138	
Improve supplier's quality to reduce costs.	2972.4		2.94		500		5		0.069	
Challenge and reduce minimum order quantities.	495.4		0.49		125		5		0.138	
Improve suppliers on time delivery performance.	1981.6		3.92		125		30		0.138	
Set up a supplier managed inventory programs.;	2972.4		3.92		500		30		0.207	
45 sets of contributions in Total.										

Table 7.4: GP Data collection of Shinawatra Thai silk

Source: Organised by author

Actions (Shinawatra Thai Silk)		Difficulty Levels				
		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.					
X2	Negotiate lower lead times with suppliers.					
X3	Reduce the number of part numbers carried.					
X4	Take credit and track your efforts to reduce inventory.					
X5	Find ways to reduce surplus and obsolete inventory.					
X6	Improve supplier's quality to reduce costs.					
X7	Challenge and reduce minimum order quantities.					
X8	Improve suppliers on time delivery performance.					
X9	Set up a supplier managed inventory programs.					
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Table 7.5: Difficulty Levels of Actions for GP Analysis of Shinawatra Thai silk

Source: Organised by author

7.2.1 Goal Programming Analysis of Shinawatra Thai silk.

Actions		Actions		Actions	
X(1)	0.000000	X(1)	1.000000	X(1)	1.000000
X(2)	0.000000	X(2)	0.000000	X(2)	0.000000
X(3)	1.000000	X(3)	0.000000	X(3)	0.000000
X(4)	1.000000	X(4)	1.000000	X(4)	0.000000
X(5)	0.000000	X(5)	1.000000	X(5)	1.000000
X(6)	0.000000	X(6)	0.000000	X(6)	0.000000
X(7)	0.000000	X(7)	1.000000	X(7)	0.000000
X(8)	1.000000	X(8)	0.000000	X(8)	1.000000
X(9)	0.000000	X(9)	0.000000	X(9)	0.000000
Remark: ALPHA = 0		**Remark: ALPHA = 0.5**		**Remark: ALPHA = 1**	

Table 7.6: The Actions Selected for Shinawatra Thai silk using the GP variants

Source: Organised by author

Table 7.6 represents the results of GP analysis which consisted of Weighted, Extended, and Chebyshev, respectively. Weighted variant suggests that action No.3, 4 and 8 are the most suitable for this manufacturer. Extended variant suggests action No. 1, 4, 5, and 7. Chebyshev variant suggests action No. 1, 5, and 8. The actions are as the follows;

Action No. 1: Work with suppliers to improve communications in the supply chain,

Action No. 3: Reduce the number of part numbers carried,

Action No. 4: Find ways to reduce surplus and obsolete inventory,

Action No. 5: Set up a business partnership with agents and distributors,

Action No. 7: Challenge and reduce minimum order quantities.

Action No. 8: Improve marketing and sale departments.

According to the experiences of this experiment, when these optimal solutions are proposed to the manufacturer. The key decision maker suggested that some of the given solutions had been undertaken before as the company aims to boost up the “turnover rate” which is the company’s first priority (same as for the AHP analysis chapter). The key decision maker however points out that he considers the solution No. 1, 5, and 8 to be a new business policy in order to improve sales performance.

7.3 The Experiments of Classic Model co. ltd.

This section is the data collection for the GP models. Table 7.7 represents the sets of contributions answered by Classic Model's key decision maker. Table 7.8 represents the difficulty levels to implement the actions.

Classic Model	Goals				
Actions	minimise inventory cost for one order (TH Baht)	minimise space used for one order in inventory (squre metre)	minimise budget for one order in inventory (TH Baht)	maximise delivery Time rate (Percentage)	maximise turnover ratio (Up to 1)
	Avg. / Target	Avg. / Target	Avg. / Target	Avg. / Target	Avg. / Target
	9387 / 8000	8.8 / 5	800 / 700	88 / 100	0.83 / 1
Work with suppliers to improve communications in the supply chain.	939	0.88	80	18	0.08
Negotiate lower lead times with suppliers.	2347	2.64	80	26	0.08
Reduce the number of part numbers carried.	2816	3.52	240	18	0.08
Take credit and track your efforts to reduce inventory.	1877	2.64	80	4	0.25
Find ways to reduce surplus and obsolete inventory.	939	3.52	200	4	0.33
Improve supplier's quality to reduce costs.	2816	3.52	320	9	0.08
Challenge and reduce minimum order quantities.	469	0.44	160	4	0.17
Improve suppliers on time delivery performance.	2347	2.64	160	18	0.17
Set up a supplier managed inventory programs.;	3755	2.64	400	26	0.33

Table 7.7: GP Data collection of Classic Model co. ltd.

Source: Organised by author

Actions		Difficulty Levels				
		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.	■				
X2	Negotiate lower lead times with suppliers.				■	
X3	Reduce the number of part numbers carried.			■		
X4	Take credit and track your efforts to reduce inventory.	■				
X5	Find ways to reduce surplus and obsolete inventory.		■			
X6	Improve supplier's quality to reduce costs.				■	
X7	Challenge and reduce minimum order quantities.			■		
X8	Improve suppliers on time delivery performance.			■		
X9	Set up a supplier managed inventory programs.				■	
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Table 7.8: Difficulty Levels of Actions for GP Analysis of Classic Model co. ltd.

Source: Organised by author

7.3.1 Goal Programming Analysis of Classic Model co. ltd.

Actions		Actions		Actions	
X(1)	0.000000	X(1)	1.000000 ✓	X(1)	0.000000
X(2)	0.000000	X(2)	0.000000	X(2)	0.000000
X(3)	0.000000	X(3)	0.000000	X(3)	1.000000 ✓
X(4)	0.000000	X(4)	0.000000	X(4)	0.000000
X(5)	1.000000 ✓	X(5)	0.000000	X(5)	1.000000 ✓
X(6)	0.000000	X(6)	0.000000	X(6)	0.000000
X(7)	0.000000	X(7)	0.000000	X(7)	0.000000
X(8)	0.000000	X(8)	0.000000	X(8)	1.000000 ✓
X(9)	1.000000 ✓	X(9)	1.000000 ✓	X(9)	0.000000
Remark: ALPHA = 0		**Remark: ALPHA = 0.5**		**Remark: ALPHA = 1**	

Table 7.9: The Actions Selected for Classic Model co. ltd using the GP variants

Source: Organised by author

Table 7.9 represents the results of GP analysis which consisted of Weighted, Extended, and Chebyshev, respectively. Weighted variant suggests that action No.5, and 9 are the most suitable for this manufacturer. Extended variant suggests action No. 1, and 9. Chebyshev variant suggests action No. 3, 5, and 8. The actions are as the follows;

Action No. 1: Work with suppliers to improve communications in the supply chain.
Action No. 3: Reduce the number of part numbers carried.
Action No. 5: Find ways to reduce surplus and obsolete inventory.
Action No. 8: Improve suppliers on time delivery performance.
Action No. 9: Set up a supplier managed inventory programs.

According to the experiences of this experiment, when these optimal solutions are proposed to the manufacturer. The key decision maker suggested that action No. 1 and 8 had been undertaken before as the company aims to boost up the “Delivery time rate” which is the company’s first priority (same as for the AHP analysis chapter). The key decision maker also suggested that he may attempt to considers the solution No. 9 with the idea of a supplier managed inventory programs to reduce the amount of total inventory. There are many popular programs used today such as: Vendor managed inventory (VMI), Point of sale (POS) and Consignment stocking (Cavinato and Kauffman, 2000).

7.4 The Experiments of Paothong Thai Silk co. ltd.

This section is the data collection for the GP models. Table 7.10 represents the sets of contributions answered by Paothong Thai Silk's key decision maker. Table 7.11 represents the difficulty levels to implement the actions.

Paothong Thai Silk	Goals									
Actions	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	12387	8000	7.1	5	1000	800	90.5	100	0.8	1
Work with suppliers to improve communications in the supply chain.	1239		0.7		100		36.2		0.16	
Negotiate lower lead times with suppliers.	3716		1.4		100		27.15		0.04	
Reduce the number of part numbers carried.	3716		2.1		200		18.1		0.04	
Take credit and track your efforts to reduce inventory.	1858		1.4		100		18.1		0.04	
Find ways to reduce surplus and obsolete inventory.	1239		2.8		200		18.1		0.04	
Improve supplier's quality to reduce costs.	5574		2.1		400		9.05		0.08	
Challenge and reduce minimum order quantities.	619		0.4		100		9.05		0.16	
Improve suppliers on time delivery performance.	3716		2.1		100		27.15		0.16	
Set up a supplier managed inventory programs.;	3716		3.2		400		36.2		0.56	

Table 7.10: GP Data collection of Paothong Thai Silk co. ltd.

Source: Organised by author

Actions		Difficulty Levels				
		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.		■			
X2	Negotiate lower lead times with suppliers.			■		
X3	Reduce the number of part numbers carried.		■			
X4	Take credit and track your efforts to reduce inventory.		■			
X5	Find ways to reduce surplus and obsolete inventory.		■			
X6	Improve supplier's quality to reduce costs.				■	
X7	Challenge and reduce minimum order quantities.			■		
X8	Improve suppliers on time delivery performance.		■			
X9	Set up a supplier managed inventory programs.				■	
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Table 7.11: Difficulty Levels of Actions for GP Analysis of Paothong Thai Silk co. ltd.

Source: Organised by author.

7.4.1 Weighted Goal Programming Analysis of Paothong Thai Silk co. ltd.

Actions	
X(1)	0.000000
X(2)	0.000000
X(3)	0.000000
X(4)	0.000000
X(5)	0.000000
X(6)	0.000000
X(7)	0.000000
X(8)	1.000000 ✓
X(9)	1.000000 ✓

Remark: ALPHA = 0

Actions	
X(1)	1.000000 ✓
X(2)	1.000000 ✓
X(3)	1.000000 ✓
X(4)	0.000000
X(5)	0.000000
X(6)	0.000000
X(7)	0.000000
X(8)	1.000000 ✓
X(9)	0.000000

Remark: ALPHA = 0.5

Actions	
X(1)	0.000000
X(2)	1.000000 ✓
X(3)	0.000000
X(4)	0.000000
X(5)	0.000000
X(6)	0.000000
X(7)	1.000000 ✓
X(8)	1.000000 ✓
X(9)	0.000000

Remark: ALPHA = 1

Table 7.12: The Actions Selected for Paothong using the GP variants

Source: Organised by author

Table 7.12 represents the results of GP analysis which consisted of Weighted, Extended, and Chebyshev, respectively. Weighted variant suggests that action No.8, and 9 are the most suitable for this manufacturer. Extended variant suggests action No. 1, 2, 3, and 8. Chebyshev variant suggests action No. 2, 7, and 8. The actions are as the follows;

Action No. 1: Work with suppliers to improve communications in the supply chain.

Action No. 2: Negotiate lower lead times with suppliers.

Action No. 3: Reduce the number of part numbers carried.

Action No. 7: Challenge and reduce minimum order quantities.

Action No. 8: Improve suppliers on time delivery performance.

Action No. 9: Set up a supplier managed inventory programs.

According to the experiences of this experiment, when these optimal solutions are proposed to the manufacturer. The key decision maker originally aims to boost up the “Delivery time rate” which is the company’s first priority (same as for the AHP analysis chapter). The key decision maker agrees that actions No. 8 and 9 are the top choices to be invested.

7.5 Summary of Goal Programming Analysis

This chapter specifically focused on an analysis of inventory optimisation where Goal Programming models were analysed in order to obtain the optimal sets of actions, which were suitable for each case study of manufacturers. There were three specific GP models used for an analysis in this chapter as follows; Weighted, Chebyshev, and Extended. In term of the optimisation, the goals used in the GP models were identified as same as decision variables seen in the AHP analysis chapters, which consisted of inventory cost, inventory space, budget, delivery time, and turnover. The useable AHP values can be seen in Table 5.13 (see in Chapter 5). The orientation of the models' analysis was presented where objectives and goals were introduced in order to implement an analysis. There were four orientations, which included specific goals to be achieved and a set of actions to achieve the goals (see table 7.1), contribution sets between actions and goals, and difficulty level to implement those actions.

There are nine specific actions presented by Cavinato and Kauffman (2000) for a contribution of inventory improvement. The actions consisted of working with suppliers to improve communications, negotiate with suppliers for lower lead times, reduce the number of spare parts, take credit and track your efforts to reduce inventory, reduce surplus and obsolete inventory, improve supplier's quality to reduce costs, challenge and reduce minimum order quantities, improve suppliers on time delivery performance, and set up a supplier managed inventory program.

Considering the above information, there were 45 sets of the contributions in total (5 Goals for 9 Actions). Key decision makers then provided those required information in order to obtain the actual values (see table 7.2). After contribution values were obtained, decision makers then answered how they felt in term of difficulty levels for implementing those actions (see table 7.3). After the orientations of the models' analysis were completed, the experiment sections were ready. The selected computer software for analysis was LINGO. The results are summarised in Table 7.13.

	Shinawatra			Classic model			Paothong		
	GP variants			GP variants			GP variants		
Actions	Weighted	Chebyshev	Extended	Weighted	Chebyshev	Extended	Weighted	Chebyshev	Extended
X1		■	■			■			■
X2								■	■
X3	■				■				
X4	■		■						■
X5		■	■	■	■				
X6									
X7			■					■	
X8	■	■			■		■	■	■
X9				■		■	■		

Table 7.13: Summary Table of GP Models' Analysis

Source: Organised by author

In terms of frequently chosen actions provided by the models (see table 7.13), action no.1, 4, 5, and 8 are repeatedly suggested to Shinawatra. Actions no. 2, and 8 are suggested to Classic Model and Paothong. There is a consistency in the selection of action no. 8, which is to improve suppliers on time delivery performance. Cavinato and Kauffman (2000) state that one of the reasons that extra inventory is carried is to compensate for suppliers who cannot be counted on to deliver on time. When consider never chosen actions, no.6 is the one that the models do not suggest to the companies. Action no.6 is to improve supplier's quality to reduce costs. Poor supplier quality will result in added costs in many areas including additional inventory as well as the cost of rejections, rework, warranty, inspection and excessive expediting (Cavinato and Kauffman, 2000). However, action no.6 might be too difficult from the companies' perspective as the difficulty level of the action is rated at 8 (very hard). After all, it depends what circumstances each solution should be adopted: Weighted GP for optimisation, Chebyshev GP for balance, and extended GP for a mixture between optimisation and balance.

7.6 Conclusion

In this chapter, the GP models were used in order to provide the set of optimal solutions to consider in order to achieve to inventory management optimisation. The key decision makers provided the information regarding the values of contribution sets. After the values were obtained, the key decision makers then answered the difficulty levels associated with implementing the set of actions. After the orientations for the models were completed, we are able to receive the set of optimal solutions for each individual manufacturer.

According to the experiences of this experiment, it depends on which of the GP variants we take into consideration for the different optimal solutions we suggest (see table 7.13). However, if we take Shinawatra Thai Silk as an example and to combine the results obtained from the three GP variants as a whole, we can conclude that there are six suggested solutions that the manufacturer might take actions on in order to improve their business. However, the decision maker points out that the solution No. 1, 5, and 8 are the most applicable for improving turnover rate. Those solutions are: work with suppliers to improve communications in the supply chain, set up a business partnership with agents and distributors, improve marketing and sale departments. After all the experiment chapters have been completed, the next chapter will give conclusions and recommendations of the research.

Chapter 8 Conclusion and Recommendation

The conclusions of this study are related back to the original research questions raised in section 1.3. The conclusion of this thesis is concluded in Section 8.1. The research findings are explained in Section 8.2. The major contributions of this study are discussed in Section 8.3 and limitations and future study is explained in Section 8.3.

8.1 Conclusion of this study

The goal of this PhD research is to contribute towards developing supply chain and inventory strategic models that support policy decisions of the Thai government and the key decision makers. The research first analyses the constraints that restrict the expansion of Thailand's silk industry. The research then critically evaluates the existing textile supply chain in the Thai Silk Industry. Operational research (OR) models were undertaken to measure efficiencies of the chosen Thai silk manufacturers' exiting suppliers and inventory management as case studies in primary research and suggest improvements.

The research starts with a literature review of the area of textile logistics and current supply chain practices. The multiple objectives, constraints, goals and stakeholders involved are systematically categorised. Data for an analysis is collected pertinent to the Thai silk industry. Case studies are developed. These case studies are then be analysed by using OR models. An Algebraic model is formulated and techniques as; Analytical Hierarchy Process, Data Envelopment Analysis (DEA), and Goal programming (GP). The experiments suggest improvements in the decision making process and configuration of the supply chain and manufacturers' inventory management.

8.2 RESEARCH FINDINGS

Revisiting the proposed Research Questions in Chapter 1, the following section presents a brief summary of the key findings in accordance with of the each individual research questions.

Research question 1. *What are specific problems in Thailand's silk industry?*

To answer the question, the literature review chapter must be first undertaken in order to understand an overview conditions of Thailand Textile Industry. Statistical data was then reviewed. We have found that Thailand had done well regarding the trade balance with almost a hundred percent from the major markets, except China. Fabric categories including silk were identified as balance problems. After we understand the conditions of the textile industry in general, the supply chains of the Thai Silk Industry were in-depth reviewed to find out if specific problems could be identified? Stakeholders of the Thai Silk Industry and Key Issues within the Thai Silk Factory were reviewed. The study show very clearly that there were specific problems identified. The problems are as follows; Product Problems, Inventory Management Problems, Management Problems, Marketing Problems and Supply Chain Problems.

Research question 2. *Which of those problems will the research carry on for further study?*

The second Research Question can be answered by looking to (section 2.10 and 2.11) in the literature review chapter. The sections are "Supply Chain Management" and "Inventory Management" respectively. According to (2.10), we focus on some key components of supply chain management. In terms of supply chains, we define as a set of three or more entities which directly involved in the upstream and downstream flows of products, services, finances, and information from a source to a customer. To create an effective supply chain, good management is needed to achieve the single or multiple objectives of the supply chain (Hamontree, 2014). In terms of Inventory Management , the inventory is the basic function to protect the supply of goods from demand changes.

Since costs are associated with inventories, they need to be dealt with in an effective, efficient, and economic manner. Following the mentioned information, they emphasise the degree of importance of those managements. Therefore, “Supply Chain” and “Inventory Management” are chosen for the primary research topics of this thesis.

Research question 3. *In terms of reliability of the research, how will the Thai silk industry be impacted by outcomes of this research?*

To answer the question, we look back to 1.4 section in Chapter 1. To achieve desired information from the companies, the research is able to have existing contacts within the Queen Sirikit Institute of Sericulture, the Federation of Thai Industries, the Thai Textile Clothing Membership Organisation, and The Queen Sirikit Department of Sericulture. These organisations had agreed to cooperate with the research. The final outcomes of this thesis are directly proposed to the case studies, and then forwarded to those mentioned organisations. Therefore, it depends on their policies how they consider the outcomes.

Research question 4. *What kind of OR models can be used in order to solve the identified problems?*

In order to answer this research question, we had studied the literature and then found that Operational Research (OR) had made a vital contribution in the wider textile and clothing areas, resource and distribution improving the cost-efficiency for the achievements. Therefore, in this thesis, the OR models are used to discover constraints in Thailand's silk industry regarding supply chain and inventory management. Algebraic models were formulated and sequentially used as follows: Analytical Hierarchy Process (AHP) is used for optimal decision making for the manufacturers’ owner or key decision makers, Data Envelopment Analysis (DEA) is used for measuring an efficiency regarding manufacturers’ existing suppliers and inventory management, and Goal programming (GP) is undertaken for optimising planning decisions in the presence of multiple conflicting objectives regarding inventory management.

Research question 5. *What supply chains and inventory solutions can be proposed to key decision makers after elicitation of their professional preferences?*

To answer the question, we have to examine the experimental processes, which are as follows; decision making analysis using the Analytic Hierarchy Process (AHP), solving inconsistencies in pairwise comparisons from AHP, efficiency analysis using Data Envelopment Analysis (DEA). And finally, we are able to propose the set of optimal solutions to the key decision makers by using Goal-Programming

8.3 Research Contributions

The key highlights of the proposed research contributions are discussed in this section. Revisiting the proposed Research objectives in Chapter 1, the following section presents a summary of the contributions derived from the main objectives as follows;

Research Contribution 1. derived from objective 1: *To analyse the constraints that restrict the expansion of Thailand's silk industry in wider global trading networks.*

The first contribution is that we gain a better understanding of overall Textile industry in Thailand. Considering in-depth statistical data for each major market, the study provides a clear vision in term of competitive advantages and disadvantages compared to other countries. The study shows that Thailand has a negative balance of trade to China, with silk identified as one of the problems. The Thai Ministry of Agriculture and Cooperatives (2010) also identified that there are exiting constraints that limit the expansion of Thailand's silk, and silk products, in international markets and trading networks. This contribution helps us to understand the importance of critical research which means to provide strategic adaptations that the industry can use to reduce the constraints in order to respond to global competitiveness.

Research Contribution 2. derived from objective 2: *To critically analyse existing supply chain of the Thai Silk Industry.*

The second contribution provides a better understanding of the supply chains of the Thai silk industry. We discovered that there are three major chains as follows; 1. Upstream supply-chains consist of silk farmers and other stakeholders, such as silk factories and Queen Sirikit Sericulture Centre, 2. process supply-chains consist of weaving activities individually or collectively, 3. downstream supply-chains consisting of retailers and wholesalers. Downstream stakeholders take part as distributors for semi and finished silk goods. The study shows that there has been the qualities' classification, which help to identify product values (see section 2.7). The contribution also helps us to know who are the stakeholders in the industry, which consist of farmers, silk yarn producers, weavers, final product producers, and marketers. Finally, we find out what are the problems in the real world Thai silk manufacturers, which refer to the case study studied by the group of professional researchers (Textiles Supply Chain Development Handbook, 2008). The major problem were identified as follows; Product Problems, Inventory Management Problems, Management Problems, Marketing Problems and Supply Chain Problems. At this point, we can look back to the answer of "Research question 2". Supply Chain and Inventory Management had been chosen for a primary research.

Research Contribution 3. derived from objective 3: *To critically apply operational research models to the case studies in order to identify the key decisions of the company owners and in order to measure the efficiency of the companies.*

The third contribution provides us a scientific method to solve the chosen problems. Firstly, AHP is used to provide quantitative priorities for decision support. The results of AHP show that key decision makers from each of companies have their own personal management policy. Therefore, we saw various types of weighting priorities based on AHP questionnaires. Secondly, the AHP results however must be validated by consider the Consistency Index (CI) and Consistency Ratio (CR) values, which must be less than 0.1 (10%). For solving the problem, a specific Goal Programming model was used. After solving those inconsistent AHP matrices, the CR values had become less than 0.1 (10 %) which is acceptable (see the example in Table 8.1).

Supplier Selection of Shinawatra			Decision in Inventory Management of Shinawatra		
	Original weights	Adjusted weights		Original weights	Adjusted weights
Product Quality	0.37	0.36	Inventory Cost	0.17	0.12
Service Level	0.42	0.45	Inventory Space	0.11	0.15
Management	0.15	0.15	Budget Constraint	0.23	0.20
Financial Flow	0.06	0.06	Delivery Time	0.20	0.21
			Turnover rate	0.29	0.32
CR	**0.13**	**0**	**CR**	**0.22**	**0.063**

Table 8.1: The summary table of the adjusted consistency ratios
Source: Organised by author

Thirdly, the study helps to identify efficiency scores regarding suppliers and inventory management of the manufacturers by using DEA. This analysis provides key decision makers a clear vision to find out where are the problems to pay more attention to when selecting their suppliers and considering the past inventory activities for a better decision in the future (see the example in Table 8.2).

Suppliers' Efficiency Analysis				Inventories' Efficiency Analysis	
	Suppliers	**DEA Scores**		**Sample Orders**	**DEA Scores**
Shinawatra	Supplier-1	**0.73**		Convertible neck	**0.7**
	Supplier-2	**0.67**		Boat neck-1	**1**
	Supplier-3	**0.9**		Mandarin neck	**1**
	Supplier-4	**1**		Shawl neck	**1**
	Supplier-5	**0.79**		Round neck-1	**0.52**

Table 8.2: The summary table the efficiency analysis
Source: Organised by author

Fourthly, to boost efficiency, the research engaged with inventory management strategic decision optimisation using the developed GP models. This study helps to provide the set of optimal solutions for inventory management based on the policy of key decision makers.

Research Contribution 4. derived from objective 4: *To develop optimal solutions for inventory management that supports policy decisions for key decision makers in the Thai silk industry.*

The fourth contribution is the ultimate one that provides directions of supply chains and inventory management to the key decision makers in the Thai silk industry. As mentioned goal-programming models are used as the analytic tools for this purpose. The nature of the optimal solution presented is depended on which of the GP variants are used, with their associated underlying philosophies. We may take “Shinawatra Thai Silk” which is a large scale manufacturer as an example. We can conclude that there are six suggested solutions in total, that “Shinawatra Thai Silk” might consider to follow those recommended solutions in order to improve their business. The suitable actions are categorised by GP variants used as follows;

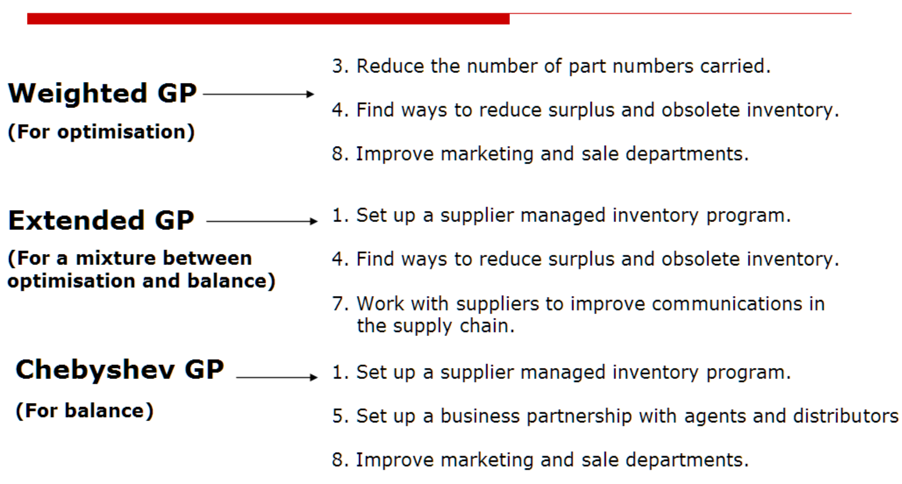

Figure 8.3: The most effective actions for Shinawatra chosen by different GP models

Source: Organised by author

8.4 Limitations and Suggestions for Further Research

Any study encounters limitations, and this study is no exception. The limitations in this study can provide potential directions for further research.

Firstly, this study only successfully interviewed eight key decision makers out of over two hundred from different Thai silk manufacturers. Future research can try to expand the number of participants; in that case, the optimal solutions or research results may have different results or concepts. In addition to the research outcomes, goal programming has been showed to be a flexible tool for modelling and combined decision maker preferences and philosophies to the Thai silk industry. And goal programming is often used as part of a larger decision support system in combination with other MCDM techniques, and other OR technique. This study however only used two of OR technique as; AHP and DEA. Further combined research methods will be able to suggest how to improve the industry from different perspectives.

Secondly, other qualitative approaches (such as a focus group or Delphi studies) could be adapted to construct the weights of each variable. The Delphi technique is a widely used and accepted method for gathering data from respondents within their domain of expertise. The technique is designed as a group communication process which aims to achieve a convergence of opinion on a specific real-world issue (Hsu and Sandford, 2007). Thirdly, the application of using combined OR technique can be further applied with different industrial activities in Thailand not only with the Thai silk. Fourthly, the final contribution of this research only suggested improved solutions with the context of the manufacturers current set of suppliers and inventory management processes. However, there will not be any impact to the industry if those manufacturers take no further actions after being suggested.

Finally, only major Thai silk manufacturers were selected in this research in order to give the thesis a coherent direction and scope. It is therefore recommended that future research apply this study to other manufacturers or other industries will increase the confidence in regard to the applicability of the research models presented.

References

Aastrup, J. and Halldorsson, A. (2008). “Epistemological role of case studies in logistics: A critical realist perspective”, International Journal of Physical Distribution & Logistics Management, 38(10), pp. 746-763.

Ahmad, Maizah. Adnan, Robiah. Daud, Zalina Mohd. and Kong, Lau chik. (2005). “A Goal Programming Approach for The Problems Analyzed Using The Method of Least Squares”. University of Technology Malaysia.

Adhikari, Samirranjan. (2009). “Strategic Educational Planning Based on Fuzzy Cognitive Mapping and Goal Programming Technique– to Develop a Tool”. University of Kalyani.

Appelbaum, R. P. (2008). “Giant transnational contractors in East Asia: emergent trends in global supply chains”. Journal of Competition & Change, Vol. 12(No. 1), pp. 69-87.

Berg, S. (2010). "Water Utility Benchmarking: Measurement, Methodology, and Performance Incentives." International Water Association.

Beynon, Malcolm. (2002). “DS/AHP method: A mathematical analysis, including an understanding of uncertainty”. European Journal of Operational Research 140 (2002) 148–164.

Bryman, A. (2008). “Why do researchers integrate/combine/mesh/blend/mix/merge/ fuse quantitative and qualitative research”. In: Bergman, M.M. ed. *Advances in mixed methods research*. London: Sage.

Bryman, A. and Bell, E. (2007). “Business Research Method”, 2nd ed. Oxford: Oxford University Press.

Brans, J.P., Gallo, G., (2007). "Ethics in OR/MS: past, present and future". Annals of Operations Research 153, 165–178.

Beil, Damian. (2009). “Supplier Selection”. Stephen M. Ross School of Business.

C.Y. Wong, S. Boon-itt. (2008). “The influence of institutional norms and environmental uncertaintyon supply chain integration in the Thai automotive industry”. Journal of Production Economics 115. pp. 400–410.

Cavinato, Jo.,& Kauffman, Ralph G., (2000), "Inventory Management" , Purchasing Handbook Sixth Edition, New York: McGraw-Hill, Chapter 26

Chansarn, Supachet (2008). "The Relative Efficiency of Commercial Banks in Thailand: DEA Approach". Journal of Finance and Economics(Issue 18).

Chen, Yun., Yu, Jia., and Khan, Shahbaz. (2013). “The spatial framework for weight sensitivity analysis in AHP-based multi-criteria decision making”. Journal of Environmental Modelling & Software.

Charnes, A., Cooper,W. and Rhodes, E. . (1978). "Measuring the efficiency of decision making units". Journal of Operations Research, No.2.

Curran, L. (2007). “Clothing’s big bang: the impact of the end of the ATC on developing country clothing suppliers”. Journal of Fashion Marketing and Management, Vol. 11(No. 1), pp. 122-134.

Crowe, Sarah. (2011). “The case study approach”. BMC Medical Research Methodology.

Conway, S. (1992). "Thai Textiles". Bangkok: River Books Press.

Carter, C.R., Easton,P.L. (2011). "Sustainable supply chain management: evolution and future directions". Int.J.Phys.Distrib.Logist.Manag.41(1),46–62.

Chopra, S. and Meindl, P. (2007) "Supply chain management. Strategy, planning & operation". Springer.

Denscombe, M. (2003). “The Good Research Guide for Small-Scale Social Research Projects”. 2nd ed. Maidenhead: Open University Press.

Escobar, M.T., Aguarón, J., and Moreno-Jiménez, J.M. (2004). “A note on AHP group consistency for the row geometric mean priorization procedure”. European journal of operational research 153(2), pp. 318-322.

EU-Thailand Small Projects Facility. (2007). “Value Chain Analysis for Thai Home Textiles Silk Sub-sector”. Institute for Science and Technology Research and Development Chiang Mai University.

Flavell, R.B. (1976). “A new goal programming formulation”, Omega, 4, 731-732.

Gass, S.I. (1986). “A Process for Determining Priorities and Weights for Large-scale Linear Goal Programmes”. Journal of Operational Research Society, 37:pp.779-785.

Graham, Mark. (2008). "New Silks Roads: Promises And Perils of the Internet in the Thai Silk Industry". PhD., University of Kentucky.

————————. (2011). "Disintermediation, Altered Chains and Altered Geographies the Internet in the Thai Silk Industry ". The Electronic Journal on Information Systems in Developing Countries, 45, 5, 1-25.

Giannoccaro, Ilaria. (2002). “Inventory management in supply chains: a reinforcement learning approach”. International Journal of Production Economics. Volume 78, Issue 2.

Ghauri, P. N. and Grønhaug, K. (2002). “Research methods in business studies”: A practical guide. London: Pearson Education.

Ghiani, G., Laporte, G. and Musmanno, R. (2004). “Introduction to logistics systems planning and control”. John Wiley & Sons.

Gold, S. ,Seuring,S., Beske,P.,2010. "Sustainable Supply Chain Management and Inter-Organizational Resources: A Literature Review". Corp. Soc. Responsib. Environ. Manag.17(4),230–245.

Gonzalez-Pach, J.and, Romero, C.. (2003). A method for dealing with inconsistencies in pairwise comparisons, European Journal of Operational Research 158 351–361.

Guneri, Ali Fuat. (2011). “An approach based on ANFIS input selection and modeling for supplier selection problem” Journal of Expert Systems with Applications. Volume 38, Issue 12.

Harris, F. (1915). “What quantity to make at once”. The library of factory management, 5, pp. 47-52.

Hadley, G. and Whitin, T. M. (1963). “Analysis of inventory systems”. Prentice Hall.

Haggblade, S. (2006)." Rural Nonfarm Dynamics. In Beyond Agriculture: The Promise of the Rural Economy for Growth and Poverty Reduction". Rome: FAO.

Halldorsson, A., Kotzab,H., Skjøtt-Larsen,T., (2009). "Supply Chain Management on the Crossroad to Sustainability:a blessing or a curse?". Logist.Res.1,83–94.

Haggblade, S., and N. Ritchie. (1992). "Opportunities for Intervention in Thailand's Silk Subsector". In GEMINI Working Paper No.27. Bethesda, Maryland: Development Alternatives, Inc.

Hsu, Chia-Chien. Sandford, Brian A. (2007). "The Delphi Technique: Making Sense of Consensus". Practical Assessment, Research & Evaluation, Vol 12, No 10.

Ishizaka Alessio, Labib Ashraf. (2009). "Analytic Hierarchy Process and Expert Choice: Benefits and Limitations". OR Insight, 22(4), pp. 201–220.

Ignizio, J. P. (1976) "Goal programming and extensions", Lexington Books, Lexington, MA.

Ignizio, J. P. (1982). "Linear Programming in Single & Multiple Objective Systems". Prentice-Hall, New Jersey.

Jadid, Omid et al. (2014). "An improved multi-choice goal programming approach for supplier selection problems". Journal of Applied Mathematical Modelling.

Jantaka, Chomphak and Tangjaturasopon, Ajcharapan. (2012). "Barriers of Value Chain for Development of Silk Product in Nakhonchaiburin Zone, Thailand". International Conference on Economics, Business Innovation IPEDR vol.38.

Jones, D.F. and Mardel, S.J. (2004). "A Distance-metric Methodology for the Derivation of Weights from a Pairwise Comparison Matrix". Journal of Operational Research Society, 55: pp. 869-875.

Jones, D.F. and Tamiz, M. (2010). "Practical Goal Programming", Springer Books.

Komolavanij, Somrote. et al, (2008). "Textiles Supply Chain Development Handbook", December 2008.

Kwangyeol, Ryu. Ilkyeong, Moon. Seungjin, Oh. Mooyoung, Jung. (2013). “A fractal echelon approach for inventory management in supply chain networks”. Int. J. Production Economics 143 (2013) 316–326.

Krishnendu, Shaw. Ravi, Shankar. et al. (2012). “Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain”. Expert Systems with Applications 39.

Kaplan Financial Knowledge Bank. (2012). “Economic Order Quantity (EOQ)” available at:http://kfknowledgebank.kaplan.co.uk/KFKB/Wiki%20Pages/Economic%20Order%20Quantity%20%28EOQ%29.aspx. Retrieved 13 May 2014.

Kasikorn research centre (2006), “The Thai Farmers Research”, available at: www.kasikornresearch.com, Retrieved 10 December 2010.

Khorramshahgol, Reza. (2012). “An Integrated Strategic Approach To Supplier Evaluation And Selection”. International Journal of Information Technology & Decision Making. Vol. 11, No. 1 p. 55-76.

Khorramshahgol R, Azani, H. and Gousty, Y. (1988). “An integrated approach to project evaluation and selection”. IEEE Transactions on Engineering Management 35(4). pp: 265-270.

LINDO SYSTEMS. (2013), "LINGO 13.0 - Optimization Modeling Software for Linear, Nonlinear, and Integer Programming". http://www.lindo.com, Retrieved 28 January 2013.

Lin Lai, Po. (2013). “A Study on The Relationship Between Airport Privatization and Airport Efficiency an Application of Using AHP/DEA Methods”. Logistics and Operations Management Section Cardiff Business School. Cardiff University. April 2013.

Lancaster University. (2014). "What is Operational Research?". available at: http://www.lancaster.ac.uk/lums/study/masters/programmes/msc-operational-research-management-science/what-is-operational-research/. Retrieved 10 May 2014.

Lam, Jimmy K.C. Postle, R., (2006) "Textile and apparel supply chain management in Hong Kong", International Journal of Clothing Science and Technology, Vol. 18 Iss: 4, pp.265 – 277.

Li, Xiaodong,. (2008). “Multiple Objective Models for Bed Allocation in A For-Profit Hospital ”. PhD thesis, University of Portsmouth, UK.

Leon, Margarita Garza de. (2012). “Category-Led Supply Management with a Supplier Lifecycle Approach: A Case Study”. International Master of Industrial Management.

Maylor, H. and Blackmon, K. 2005. Researching Business and Management, New York: Palgrave Macmillan.

May, T. (2001). “Social research: issues, methods and process”. 3rd ed. Buckingham: Open University Press.

Martin JC and C Roman (2001). “An Application of DEA to Measure the Efficiency of Spanish Airports Prior to Privatization.” J Air Transportation Management 7(3): 149-157.

Ministry of Agriculture and Cooperatives (2010), “The Strategy of Thai Silk”, available at: http://www.moac.go.th/builder/mu/images/strate.pdf, Retrieved 11 December 2010.

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D. and Zacharia, Z. G. (2001) “Defining supply chain management”, Journal of Business logistics, 22(2), pp. 1-25.

Multi-objective optimization, (2012). http://dbpedia.org/page/Multi- objective optimization, Retrieved 9 Jan 2013.

Mikko. Kurttila et al. (2000), “Utilizing the Analytic Hierarchy Process AHP in SWOT Analysis – a Hybrid Method and its Application to a Forest- Certification Case ” ,Foresty Policy and Economics, pp. 41-52.

Mentzer, John T et al., (2001): Defining Supply Chain Management. Journal of Business Logistics, Vol. 22, No. 2, pp. 1–25.

Namchaisiri, Jane (2007). “Opportunities of Thai textiles in the Crisis” Retrieved 9 December 2011.

Oddoye, J.P. (2009). “Efficient Resource Planning in a Medical Assessment Unit Using Goal Programming and Simulation”. PhD thesis, University of Portsmouth, UK.

Oddoye, J.P., Yaghoobi M A, Tamiz M, Jones D F and Schmidt P. (2007). “A Multi-Objective Model Determine Efficient Resource Levels in a Medical Assessment Unit”. Journal of Operational Research Society, 58: pp. 1563-1573.

Ormerod, Richard J., Ulrich, Werner. (2013). "Operational research and ethics: A literature review". European Journal of Operational Research 228 (2013) 291–307.

Oguztimur, Senay. (2010). “Why Fuzzy Analytic Hierarchy Process Approach for Transport Problems?”. Yıldız Technical University Department of City and Regional Planning.

Picavet, E., (2009). "Opportunities and pitfalls for ethical analysis in operations research and the management sciences". Omega 37, 1121–1131.

Preeti Tyagi, at al. (2009). "Efficiency analysis of schools using DEA: A case study of Uttar Pradesh state in India". Department of Mathematics.

Petison, P., & Johri, L. M. (2008). "Dynamics of the manufacturer-supplier relationships in emerging markets: A case of Thailand". Journal of Asia Pacific Journal of Marketing and Logistics, Vol. 20, pp. 76-96.

PG Public Services. (2010). “Using Analytical Hierarchical Processing (AHP) Tools for Justifying Investment Requirements”, PG Public Services LLC.

Promsaka Na Sakolnakorn, Thongphon. (2009). “Management Strategy For Administration Of Textile Industries In A Developing Country: Case Study Thailand”, Journal of Business Case Studies, Volume 5, Number 3

PLEA. (2011). “27th Conference on Passive and Low Energy Architecture”, Louvain-la-Neuve, Belgium 13-15 July 2011.

Phusavat, K., & Kanchana, R. (2007). "Competitive priorities of manufacturing firms in Thailand". Journal of Industrial Management & Data, Vol.107.

Ramanathan, R. (2001). "A Note on The Use of The Analytic Hierarchy Process for Environmental Impact Assessment". Journal of Environmental Management, Vol. 63, 27-35.

Royal Danish Embassy, – Bangkok (2007). "Sector Overview Fashion Industry in Thailand April 2007". Bangkok Danish Trade Council .

Robson,C. (2002). "Real World Research ", 2nd ed. Oxford: Blackwell.

Saaty, T. (1977). "A scaling method for priorities in hierarchical structures". Journal of mathematical psychology 15 (3): 234 -281.

Saaty, T.L. (1980). “The Analytic Hierarchy Process”. New York: McGraw-Hill.

Saaty, T.J. (1990). “How to make a decision: The analytic hierarchy process”. European Journal of Operational Research, 48: 9-26.

Saaty, T.L. (1996). “Decision Making with Dependence and Feedback: The Analytic Network Process”. Pittsburgh: RWS publication.

Saaty, Thomas L.; Peniwati, Kirti (2008). “Group Decision Making: Drawing out and Reconciling Differences”. Pittsburgh, Pennsylvania: RWS Publications.

Saaty, T.L. (2008). “Decision making with the analytic hierarchy process”. Journal of service science 1(1), pp. 83-98.

Saunders, M., Lewis, P. and Thornhill, A. (2007). “Research Methods for Business Students”. 4th ed. London: Prentice Hall.

Saunders, M., Lewis, P. and Thornhill, A. (2009). “Research Methods for Business Students”. 5th ed. London: Prentice Hall.

Sarmah, S., Acharya, D. and Goyal, S. (2006) "Buyer vendor coordination models in supply chain management", European journal of operational research, 175(1), pp. 1-15.

Shapiro, Jeremy F. (2007). "Modeling The Supply Chain". London: The Thomson Corporation.

Sadrabadi, Mahmood Rezael.; Sadjadi, Seyed Jafar. (2009). “A New Interactive Method to Solve Multiobjective Linear Programming Problems”, Journal of Software Engineering & Applications, pp. 237-247.

Samoilenko, Sergey.; Osei-Bryson, Kweku-Muata. (2012). “Using Data Envelopment Analysis (DEA) for monitoring efficiency-based performance of productivity driven organizations: Designand implementation of a decision support system”, Science Direct, available online at 6 February 2012.

Schmidt, Gunther. (2010). “Relational Mathematics”. Cambridge University Press.

Seuring, S., Müller, M.,2008. "From a literature review to a conceptual framework for sustainable supply chain management".J.Clean.Prod.16(15),1699–1710.

Siu Keung Kwok, Kenny K.W. Wu. (2009) "RFID-based intra-supply chain in textile industry", Industrial Management & Data Systems, Vol. 109 Iss: 9, pp.1166 - 1178.

Scniederjans, M.J. (1995) “Goal programming methodology and applications”. Kluwer publishers, Boston.

Song, D, P. (2013). “Optimal Control and Optimization of Stochastic Supply Chain Systems”. Springer, London.

Supply Chain Management (SCM). APICS Dictionary. Retrieved 25 June 2014.

Takahagi, Eiichiro. (2005). “AHP (Analytic Hierarchy Process) Calculation software by CGI” Senshu University. Retrieved 19 April 2014.

Triantaphyllou, Evangelos. (2000). “Multi-Criteria Decision Making Methods: A Comparative Study”. Springer book; 2000 edition.

T. Johnsen, & Rhona E. (2007). "The role of focal suppliers in strategic networks for internationalisation: Perspectives from small and medium-sized Italian and Thai silk suppliers". Journal of Fashion Marketing and Management, Vol. 11.

The Royal Peacock Logo. (2014). http://www.mizpah.biz/royal-peacock-logo. Retrieved 12 May 2014.

Talluri, Srinivas. (2000). "Data Envelopment Analysis: Models and Extensions". Journal of Production/Operations Management.

Textile Digest. (2012). "Thai Fabric Export Classified by ASEAN 2011" Retrieved March- April 2012.

Textile Digest. (2012). "Thai Fabric Export Classified by Major Market 2011" Retrieved March-April 2012.

Textile Digest. (2012). "Thai Textile & Clothing Export 2011" Retrieved March-April 2012.

Textile Digest. (2012). "Thai Textile & Clothing Export Classified by ASEAN 2011" Retrieved March-April 2012.

Textile Digest. (2012). "Thai Textile & Clothing Export Classified by Major Market 2011" Retrieved March-April 2012.

Thai Textile Statistics. (2010). "Value of Exports : Textile Subsector" Retrieved 2009-2010.

Thai Textile Statistics. (2010). "Value of Imports : Textile Subsector" Retrieved 2009-2010.

Thailand Board of, Investment. (2010). "Opportunities for the Development within the Thailand's Textile Industry" Retrieved 19 April 2012.

Thailand Textile Institute. (2009). “Textile intelligence”, Retrieved 24 April 2012.

Thailand Textile Institute. (2011). "Ratio of Exportation and Importation of Thai Textile and Clothing 2011 " Retrieved 2011-2012.

The Queen Sirikit Institute of Sericulture. (2009). “The Royal Peacock Logo”, available at: http://www.qthaisilk.com/, Retrieved 10 December 2010.

The Queen Sirikit Institute of Sericulture. (2011). "Stakeholder of The Thai Silk Industry" Retrieved 19 April 2011.

TTIS Textile Digest. (2008). “Fabric today not only fashion but also function”. TTIS Textile Digest, Vol. 16(No. 156), pp. 23-27.

The Thai Silk Fabrics. (2012). "http://thumbs.dreamstime.com/thumblarge _520/1278843153WI6CHN.jpg". Retrieved 31 October 2012.

UNCTAD/WTO. (1997). "Silk Review 1997: A Survey of International Trends in Production and Trade". Geneva: International Trade Centre UNCTAD/WTO.

———. (2002). "Silk Review 2001: A Survey of International Trends in Production and Trade". Geneva: International Trade Centre UNCTAD/WTO.

Watchravesringkan, K. (2009). "The competitive position of Thailand’s apparel industry: Challenges and opportunities for globalization". Journal of Fashion Marketing and Management, Vol. 14, pp. 576-597.

Warren, W. (1970). "The Legendary American: The Remarkable Career and Strange Disappearance of Jim Thompson". Boston: Houghton Mifflin.

Wang, G., Huang, S. H., & Dismukes, J. P. (2004). Product-driven supply chain selection using integrated multi-criteria decision-making methodology. International Journal of Production Economics, 91(1), 1–15.

Wang, Ying-Ming. et al. (2008). “An integrated AHP–DEA methodology for bridge risk assessment”. Journal of Computers & Industrial Engineering 54 (2008) 513–525.

Weber, Charles A. Current, John. Desai, Anand, (2000) "An optimization approach to determining the number of vendors to employ", Supply Chain Management: An International Journal, Vol. 5 Iss: 2, pp.90 – 98.

Wilson, R. (1934). “A scientific routine for stock control”, *Harvard business review,* 13(1), pp. 116-129.

WTO, (2008), “International trade statistics 2008”, available at: www.wto.org/english/res_e/statis_e/its2008_e/its2008_e.pdf.

Yearman, K & Gluckman, A. (2005). “Falling Off a Cliff. Dollars & Sense”, http://www.dollarsandsense.org/archives/2005/0905yearman.html, Retrieved 10 April 2012.

Yin, R. K. (1984). “Case study research: Design and methods”. Newbury Park, CA: Sage.

Zhang, Zhiyong. et al. (2009)”.Cutting-Edge Research Topics on Multiple Criteria Decision Making”. Journal of Communications in Computer and Information Science Volume 35, 2009, pp 630-634.

Appendices

Appendix A

AHP Questionnaire

The Questionnaire Used for Research Only

เรื่อง การวิเคราะห์เชิงปริมาณและคุณภาพในเรื่องโลจิสติกส์ของอุตสาหกรรมไหมไทย

(Quantitative and Qualitative Analysis of the Thai Silk Industry)

__Statement of purpose__

The purpose of this questionnaire is to be used as a part of PhD research study to help the development logistic and supply chain model which supports policy decisions of the Thai government and the decision makers in the Thai silk field. The research concentrate mainly on Supply Chain and Inventory Management. The results will be used to suggest improvements in the decision making process and configuration of the Thai silk's supply chain.

The aggregated results of the questionnaire will be used for data analysis in my Ph.D. thesis and scientific publications. However, no individual company will be identified by name.

Thank you for your cooperation

....

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Questionnaire for Ph.D. Thesis

เรื่อง Quantitative and Qualitative Analysis of the Logistics of the Thai Silk Industry

Part 1 Company Information

Remark: Please fill out the blank and ☑ in which you prefer.

1a. Company name ....

Address: No: .... Street: .... region: ....District: ....

Province: ....Postal Code: ....

Tel:.................................. ......Fax:......................................E-mail:..

1b. Associated company: ....

1c. Contact Person: ....Job titles: ....

Tel: ....Fax: ....

Mobile: ....E-mail: ....

1d. Does your company want to remain anonymous? ☐ Yes ☐ No

1e. No of Machinery: .... No. of Labour: ....

Part 2

Remark: Please fill out the blank and ☑ in which you prefer.

2a. Your Products

☐ Shirt ☐ Skirt ☐ Trousers ☐ Dress ☐ Others; please specify ....

2b. Average price............Baht/unit Lowest price..................Baht Highest price..................Baht

2c. Amount of (SKUs: Stock keeping unit).. per year

Number of Style...........per year Number of Color.........per year Number of Sizes ....per year

2d. Packing Tools

☐ Carton Boxes ☐ Big bags ☐ Clothes-hanger ☐ Packing paper ☐ Others.......................

No. of products per Box: .... No. of boxes per Pallet: ....

2e. Does your company use Bar-code? ☐ Yes ☐ No

3a. **Your current business**:

Do you have domestic markets of your products?

☐ No ☐ Yes If so, please state their names..

Do you have international markets of your products?

☐ No ☐ Yes If so, please state their names..

Your characteristics in an international market:

☐ sales agents ☐ stock keeping distributors ☐ own sale force ☐ others..

You international clients' characteristics:

☐ OEM ☐ Distributors ☐ wholesaler ☐ retailer ☐ end-user

3b. **Supply Chains:** What are the production locations of your company?..

Do you use an **internal** warehouse for stocking? ☐ Yes ☐ No

Do you use an **external** warehouse for stocking? ☐ Yes ☐ No

What are the current stocking locations of your company? ....

3c. **Logistic partners**:

Do you have **domestic** logistic service providers? ☐ No ☐ Yes ....

Do you have **international** logistic service providers? ☐ No ☐ Yes ....

4a. **Order quantities:** Average number of order per month? Piece: .... Box: ....

4b. **Transportations** : Air: ....% Rail: ....% Road: ....% Water: ....%

4c. **Are there seasonal influences in the order pattern?** ☐ Yes ☐ No

4d. **Do you expect to have rush orders?** ☐ Yes ☐ No

5a. **Inventory:** Average Annual Demand of products per year: ....

Average Annual Production rate per year: ....

Average number of SKUs per year: ....

Turnover rate of stock...times per year

5b. **Inventory Cost:** Average Setup cost of machinery: ....

Average Ordering cost of your products: ....

Average Holding cost of your stocking: ....

Average Shortage Cost of your stocking: ....

5.c. **Inventory Space and Budget Constraint: Annual Budget**

Annual Budget: .... Inventory space required: ....M^2

Floor storage: .... M^2 Shelf storage: .... M^2 Bin Storage .... M^2

5d. **Are there any special storage requirements?** ☐ No ☐ Yes Please tick the box

☐ temperature controlled ☐ high security ☐ others

5d. **Are value adding activities required ?** ☐ No ☐ Yes Please tick the box

☐ assembly ☐ customisation ☐ labeling ☐ packing

Part 3 Ratio Scale of Comparative Judgments of the Thai Silk manufacturer

Remark: Please compare between left and right, then ✓ in which level you give priority from level 1-9.

Definition: 1= Equally Important 3= Moderate 5= Strong Importance
7= Very Strong Importance 9= Extreme Importance

Sample:

Process and Product Quality									Service Level							
9✓	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

6.a. Supplier Selection

Process and Product Quality									**Service Level**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Process and Product Quality									**Management and Innovation**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Process and Product Quality									**Financial Position**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Service Level									**Management and Innovation**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Service Level									**Financial Position**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Management and Innovation									**Financial Position**							
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9

6.b. Decision in Inventory Management

Inventory Cost																**Inventory Space**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Cost																**Budget Constraint**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Cost																**Delivery Time**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Cost																**Turnover rate**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Space																**Budget Constraint**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Space																**Delivery Time**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Inventory Space																**Turnover rate**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Budget Constraint																**Delivery Time**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Budget Constraint																**Turnover rate**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9
Delivery Time																**Turnover rate**
9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9

Appendix B

AHP Results

AHP Results of Supplier Selection

Kampo Thai Silk	Decision Variables	Original Rating				C.I.	0.21
		P.Q	S.L.	M	F.F.		
	Product Quality	1	8	8	8		
	Service Level	1.125	1	5	8	C.R.	0.24
	Management	1.125	0.2	1	4		
	Financial Flow	1.125	1.125	0.25	1		

PNL	Decision Variables	Original Rating				C.I.	0.49
		P.Q	S.L.	M	F.F.		
	Product Quality	1	9	1	1		
	Service Level	0.11	1	1	6	C.R.	0.54
	Management	1	1	1	1		
	Financial Flow	1	0.17	1	1		

Watchara Thai Silk	Decision Variables	Original Rating				C.I.	0.26
		P.Q	S.L.	M	F.F.		
	Product Quality	1	9	9	9		
	Service Level	0.11	1	0.17	5	C.R.	0.28
	Management	0.11	6	1	5		
	Financial Flow	0.11	0.2	0.2	1		

Chattong Thai Silk	Decision Variables	Original Rating				C.I.	0.37
		P.Q	S.L.	M	F.F.		
	Product Quality	1	8	8	8		
	Service Level	0.13	1	0.14	8	C.R.	0.41
	Management	0.13	7	1	7		
	Financial Flow	0.13	0.13	0.14	1		

Chalieo Thai Silk	Decision Variables	Original Rating				C.I.	0.19
		P.Q	S.L.	M	F.F.		
	Product Quality	1	9	9	9		
	Service Level	0.11	1	0.13	1	C.R.	0.22
	Management	0.11	8	1	1		
	Financial Flow	0.11	1	1	1		

AHP Results of Inventory Management

Kampo Thai Silk

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	4	1	1	1
Inventory Space	0.25	1	1	1	1
Budget Constraint	1	1	1	1	1
Delivery Time	1	1	1	1	1
Turnover rate	1	1	1	1	1

C.I.	0.05
C.R.	0.04

PNL

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	9	9	9	0.11
Inventory Space	0.11	1	0.11	0.1	0.1
Budget Constraint	0.11	9	1	0.1	0.1
Delivery Time	0.11	9	9	1	0.11
Turnover rate	1	9	9	9	1

C.I.	0.53
C.R.	0.48

Watchara Thai Silk

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	7	7	1	1
Inventory Space	0.14	1	7	1	1
Budget Constraint	0.14	0.14	1	0.11	1
Delivery Time	1	1	9	1	9
Turnover rate	1	1	1	0.11	1

C.I.	0.26
C.R.	0.23

Chattong Thai Silk

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	7	0.14	7	0.25
Inventory Space	0.14	1	0.14	0.13	0.14
Budget Constraint	7	7	1	0.13	0.14
Delivery Time	0.14	8	8	1	7
Turnover rate	0.14	7	7	0.14	1

C.I.	1.16
C.R.	1.04

Chalieo Thai Silk

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	0.13	1	7	0.13
Inventory Space	8	1	8	8	0.13
Budget Constraint	1	0.13	1	8	1
Delivery Time	0.14	0.13	0.13	1	0.13
Turnover rate	8	8	1	8	1

C.I.	0.41
C.R.	0.37

Appendix C

The Revised AHP Results

Kampo Thai Silk

The Revised AHP Results of Supplier Selection

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	8	8	8	0.63
Service Level	1.125	1	5	8	0.23
Management	1.125	0.2	1	4	0.09
Financial Flow	1.125	1.125	0.25	1	0.04

1X				Weights
1	1	5	8	0.43
0.99	1	5	8	0.43
0.2	0.2	1	1.6	0.09
0.125	0.125	0.625	1	0.05

6X				Weights
1	1.6	8	8	0.51
0.6249	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

2X				Weights
1	1.6	8	8	0.53
0.625	1	5	5	0.33
0.125	0.2	1	1	0.07
0.1249	1.99	0.99	1	0.07

7X				Weights
1	1.6	8	8	0.51
0.625	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

3X				Weights
1	1	5	8	0.43
0.99	1	5	8	0.43
0.2	0.2	1	1.6	0.09
0.125	0.125	0.625	1	0.05

8X				Weights
1	1.6	8	8	0.51
0.625	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

4X				Weights
1	1	5	8	0.43
0.99	1	5	8	0.43
1.99	0.2	1	1.6	0.09
0.125	0.125	0.625	1	0.05

9X				Weights
1	1.6	8	8	0.51
0.625	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

5X				Weights
1	1.6	8	8	0.51
0.625	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

10X				Weights
1	1.6	8	8	0.51
0.625	1	5	8	0.36
0.125	0.2	1	1.6	0.07
0.125	0.125	0.625	1	0.05

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.38	1.5
2X	0	0	0.49	2.96
3X	0	0	0.38	1.5
4X	0	0	0.38	1.5
5X	0.01	0	0.38	1.5
6X	0.01	0	0.38	1.5
7X	0.01	0	0.38	1.5
8X	0.01	0	0.38	1.5
9X	0.01	0	0.38	1.5
10X	0.01	0	0.38	1.5

The Revised AHP Results of Inventory Management

The original AHP result is already reliable

Decision Variables	Original Rating				
	I.C.	I.S.	B.C.	D.T.	T.R.
Inventory Cost	1	4	1	1	1
Inventory Space	0.25	1	1	1	1
Budget Constraint	1	1	1	1	1
Delivery Time	1	1	1	1	1
Turnover rate	1	1	1	1	1

Weights	C.I.	C.R.
0.28	0.05	0.04
0.15		
0.19		
0.19		
0.19		

PNL co., Ltd.

The Revised AHP Results of Supplier Selection

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	9	1	1	0.37
Service Level	0.11	1	1	6	0.26
Management	1	1	1	1	0.19
Financial Flow	1	0.17	1	1	0.17

1X				Weights
1	1	1	1	0.25
0.99	1	1	1	0.25
0.99	1	1	1	0.25
0.99	1	1	1	0.25

2X				Weights
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25

3X				Weights
1	0.99	1	1	0.25
1	1	1	1	0.25
1	0.99	1	1	0.25
1	1	1	1	0.25

4X				Weights
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25

5X				Weights
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25
1	1	1	1	0.25

6X				Weights
1	1	1	1	0.25
1	1	1	1.51	0.28
1	1	1	1	0.25
1	0.66	1	1	0.23

7X				Weights
1	9	1	1	0.39
0.111	1	1	1	0.15
1	1	1	1	0.23
1	1	1	1	0.23

8X				Weights
1	9	1	1	0.39
0.111	1	1	1	0.15
1	1	1	1	0.23
1	1	1	1	0.23

9X				Weights
1	9	1	1	0.39
0.111	1	1	1	0.15
1	1	1	1	0.23
1	1	1	1	0.23

10X				Weights
1	2.198	1	1	0.29
0.454	1	1	6	0.32
1	1	1	1	0.22
1	0.166	1	1	0.17

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.92	7.9
2X	0	0	0.92	8.0
3X	0	0	0.92	8.0
4X	0	0	0.92	8.0
5X	0	0	0.92	8.0
6X	0.01	0	0.79	8.0
7X	0.17	0.2	0.36	5.0
8X	0.17	0.2	0.36	5.0
9X	0.17	0.2	0.36	5.0
10X	0.18	0.2	0.24	3.1

The Revised AHP Results of Inventory Management

Decision Variables	Original Rating					Weights
	I.C.	I.S.	B.C.	D.T.	T.R.	
Inventory Cost	1	9	9	9	0.11	0.23
Inventory Space	0.11	1	0.11	0.1	0.1	0.02
Budget Constraint	0.11	9	1	0.1	0.1	0.07
Delivery Time	0.11	9	9	1	0.11	0.15
Turnover rate	1	9	9	9	1	0.53

1X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
0.999	9	9	1	1	0.31
0.999	9	9	1	1	0.31

2X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

3X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

4X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

5X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

6X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

7X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

8X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

9X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

10X					Weights
1	9	9	1	1	0.31
0.111	1	1	0.111	0.111	0.03
0.111	1	1	0.111	0.111	0.03
1	9	9	1	1	0.31
1	9	9	1	1	0.31

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	1.40	8.0
2X	0	0	1.40	8.0
3X	0	0	1.40	8.0
4X	0	0	1.40	8.0
5X	0	0	1.40	8.0
6X	0	0	1.40	8.0
7X	0	0	1.40	8.0
8X	0	0	1.40	8.0
9X	0	0	1.40	8.0
10X	0	0	1.40	8.0

Watchara Thai Silk

The Revised AHP Results of Supplier Selection

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	9	9	9	0.66
Service Level	0.11	1	0.17	5	0.10
Management	0.11	6	1	5	0.20
Financial Flow	0.11	0.2	0.2	1	0.04

1X				Weights
1	9	1.8	9	0.56
0.111	1	0.2	1	0.06
0.555	5	1	5	0.31
0.111	1	0.2	1	0.06

2X				Weights
1	9	1.79	9	0.56
0.111	1	0.19	1	0.06
0.555	5	1	5	0.32
0.111	1	0.19	1	0.06

3X				Weights
1	9	1.8	9	0.56
0.111	1	0.2	1	0.06
0.555	5	1	5	0.31
0.111	1	0.2	1	0.06

4X				Weights
1	9	1.8	9	0.56
0.111	1	0.2	1	0.06
0.555	5	1	5	0.31
0.111	1	0.2	1	0.06

5X				Weights
1	9	1.8	9	0.56
0.111	1	0.2	1	0.06
0.555	5	1	5	0.31
0.111	1	0.2	1	0.06

6X				Weights
1	9	1.8	9	0.56
0.111	1	0.166	1	0.06
0.555	6	1	5	0.32
0.111	1	0.2	1	0.06

7X				Weights
1	9	1.8	9	0.56
0.111	1	0.166	1	0.06
0.555	6	1	5	0.32
0.111	1	0.2	1	0.06

8X				Weights
1	9	1.8	9	0.56
0.111	1	0.166	0.999	0.06
0.555	6	1	5	0.32
0.111	1	0.2	1	0.06

9X				Weights
1	9	1.8	9	0.56
0.111	1	0.166	1	0.06
0.555	6	1	5	0.32
0.111	1	0.2	1	0.06

10X				Weights
1	9	1.8	9	0.56
0.111	1	0.166	1	0.06
0.555	6	1	5	0.32
0.111	1	0.2	1	0.06

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.62	4
2X	0	0	0.62	4
3X	0	0	0.62	4
4X	0	0	0.62	4
5X	0	0	0.62	4
6X	0	0	0.60	4
7X	0	0	0.60	4
8X	0	0	0.60	4
9X	0	0	0.60	4
10X	0	0	0.60	4

The Revised AHP Results of Inventory Management

Decision Variables	Original Rating					Weights
	I.C.	I.S.	B.C.	D.T.	T.R.	
Inventory Cost	1	7	7	1	1	0.33
Inventory Space	0.142857	1	7	1	1	0.16
Budget Constraint	0.142857	0.142857	1	0.111111	1	0.04
Delivery Time	1	1	9	1	9	0.35
Turnover rate	1	1	1	0.111111	1	0.11

1X					Weights
1	1	7	0.77	2.89	0.26
1	1	7	0.77	2.89	0.26
0.142	0.142	1	0.111	0.413	0.04
1.285	1.285	9	1	3.71	0.34
0.345	0.345	2.42	0.268	1	0.09

2X					Weights
1	1	7	0.77	2.89	0.26
1	1	7	0.77	2.89	0.26
0.142	0.142	1	0.111	0.413	0.04
1.285	1.285	9	1	3.71	0.34
0.345	0.345	2.42	0.268	1	0.09

3X					Weights
1	1	7	0.77	2.89	0.26
1	1	7	0.77	2.89	0.26
0.142	0.142	1	0.111	0.413	0.04
1.285	1.285	9	1	3.71	0.34
0.345	0.345	2.42	0.268	1	0.09

4X					Weights
1	1	7	0.77	2.89	0.26
1	1	7	0.77	2.89	0.26
0.142	0.142	1	0.111	0.413	0.04
1.285	1.285	9	1	3.71	0.34
0.345	0.345	2.42	0.268	1	0.09

5X					Weights
1	1	7	0.77	2.89	0.26
1	1	7	0.77	2.89	0.26
0.142	0.142	1	0.111	0.413	0.04
1.285	1.285	9	1	3.71	0.34
0.345	0.345	2.42	0.268	1	0.09

6X					Weights
1	1	7	0.77	3.13	0.27
1	1	7	0.77	3.13	0.27
0.142	0.142	1	0.111	1	0.05
1.285	1.285	9	1	4	0.34
0.319	0.319	2.2	0.24	1	0.08

7X					Weights
1	1	7	0.77	2.16	0.24
1	1	7	0.77	2.16	0.24
0.142	0.142	1	0.111	1	0.04
1.285	1.285	9	1	9	0.39
0.462	0.462	1	0.111	1	0.08

8X					Weights
1	1	7	0.77	1.75	0.24
1	1	7	0.77	1.75	0.24
0.142	0.142	1	0.111	1	0.04
1.285	1.285	9	1	9	0.40
0.571	0.571	1	0.111	1	0.09

9X					Weights
1	1	7	0.77	1.47	0.23
1	1	7	0.77	1.47	0.23
0.142	0.142	1	0.111	1	0.04
1.285	1.285	9	1	9	0.40
0.679	0.679	1	0.111	1	0.10

10X					Weights
1	1	7	0.77	1.26	0.22
1	1	7	0.77	1.26	0.22
0.142	0.142	1	0.111	1	0.04
1.285	1.285	9	1	9	0.40
0.792	0.792	1	0.111	1	0.11

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.68	6.0
2X	0	0	0.68	6.0
3X	0	0	0.68	6.0
4X	0	0	0.68	6.0
5X	0	0	0.68	6.0
6X	0.02	0.02	0.66	6.0
7X	0.05	0.04	0.45	6.0
8X	0.07	0.06	0.41	6.0
9X	0.08	0.07	0.38	6.0
10X	0.1	0.09	0.35	6.0

Chattong Thai Silk

The Revised AHP Results of Supplier Selection

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	8	8	8	0.60
Service Level	0.125	1	0.142857	8	0.13
Management	0.125	7	1	7	0.23
Financial Flow	0.125	0.125	0.142857	1	0.04

1X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

2X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

3X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

4X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

5X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

6X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

7X				Weights
1	8	8	8	0.73
0.125	1	1	0.99	0.09
0.125	1	1	1	0.09
0.125	1	1	1	0.09

8X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

9X				Weights
1	8	8	8	0.67
0.125	1	1	0.125	0.06
0.125	1	1	1	0.08
0.125	1	1	1	0.18

10X				Weights
1	8	1.142	8	0.47
0.125	1	0.142	1	0.06
0.874	7	1	7	0.41
0.125	1	0.142	1	0.06

	C.I.	C.R.	Average Change	Maximum Change
1X	0.16	0.18	1.36	7
2X	0.16	0.18	1.36	7
3X	0.16	0.18	1.36	7
4X	0.16	0.18	1.36	7
5X	0.16	0.18	1.36	7
6X	0.16	0.18	1.36	7
7X	0	0.00	1.35	7
8X	0.16	0.18	1.36	7
9X	0.16	0.18	1.36	7
10X	0	0.00	0.92	7

The Revised AHP Results of Inventory Management

Decision Variables	Original Rating: I.C.	I.S.	B.C.	D.T.	T.R.	Weights
Inventory Cost	1	7	0.142857	7	7	0.33
Inventory Space	0.142857	1	0.142857	0.125	0.142857	0.02
Budget Constraint	7	7	1	0.125	0.142857	0.23
Delivery Time	0.142857	8	8	1	7	0.27
Turnover rate	0.142857	7	7	0.142857	1	0.15

1X					Weights
1	7	7	0.875	0.99	0.29
0.142	1	1	0.125	0.142	0.04
0.142	1	1	0.125	0.142	0.04
1.142	8	8	1	1.142	0.33
1	7	7	0.875	1	0.29

2X					Weights
1	7	7	0.875	1	0.29
0.142	1	1	0.125	0.142	0.04
0.142	1	1	0.125	0.142	0.04
1.142	8	8	1	1.142	0.33
1	7	7	0.875	1	0.29

3X					Weights
1	7	7	0.875	1	0.33
0.142	1	0.142	0.125	0.142	0.03
1	7	1	0.875	1	0.17
1.14	8	1.14	1	1.14	0.25
1	7	1	0.875	1	0.22

4X					Weights
1	7	7	0.875	1	0.29
0.142	1	1	0.125	0.142	0.04
0.142	1	1	0.125	0.142	0.04
1.142	8	8	1	1.142	0.33
1	7	7	0.875	1	0.29

5X					Weights
1	7	7	0.875	1	0.29
0.142	1	1	0.125	0.142	0.04
0.142	1	1	0.125	0.142	0.04
1.142	8	8	1	1.142	0.33
1	7	7	0.875	1	0.29

6X					Weights
1	7	7	0.875	1	0.29
0.142	1	1	0.125	0.142	0.04
0.142	1	1	0.125	0.142	0.04
1.142	8	8	1	1.142	0.33
1	7	7	0.875	1	0.29

7X					Weights
1	7	5.56	0.875	1	0.28
0.142	1	0.79	0.125	0.142	0.04
0.179	1.25	1	0.125	0.142	0.05
1.142	8	8	1	1.142	0.34
1	7	7	0.875	1	0.30

8X					Weights
1	7	3.4	0.875	1	0.26
0.142	1	0.49	0.125	0.142	0.04
0.29	2	1	0.125	0.142	0.06
1.142	8	8	1	1.142	0.34
1	7	7	0.875	1	0.30

9X					Weights
1	7	2.34	0.875	1	0.25
0.142	1	0.33	0.125	0.142	0.04
0.142	2.98	1	0.125	0.142	0.07
1.142	8	8	1	1.142	0.34
1	7	7	0.875	1	0.30

10X					Weights
1	7	1.53	0.875	1	0.24
0.142	1	0.219	0.125	0.142	0.03
0.65	4.55	1	0.125	0.142	0.09
1.142	8	8	1	1.142	0.34
1	7	7	0.875	1	0.30

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	3.06	48
2X	0	0	3.06	48
3X	0.1	0.09	3.33	48
4X	0	0	3.06	48
5X	0	0	3.06	48
6X	0	0	3.06	48
7X	0	0	2.60	38
8X	0.02	0.02	1.90	23
9X	0.04	0.04	1.56	15
10X	0.08	0.07	1.29	10

Chalieo Thai Silk

The Revised AHP Results of Supplier Selection

Decision Variables	Original Rating				Weights
	P.Q	S.L.	M	F.F.	
Product Quality	1	9	9	9	0.70
Service Level	0.11	1	0.13	1	0.06
Management	0.11	8	1	1	0.17
Financial Flow	0.11	1	1	1	0.08

1X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

2X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

3X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

4X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

5X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

6X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

7X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	0.99	1	1	0.08
0.111	1	1	1	0.08

8X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	1	1	1	0.08
0.111	1	1	1	0.08

9X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	0.99	1	1	0.08
0.111	1	1	1	0.08

10X				Weights
1	9	9	9	0.75
0.111	1	1	1	0.08
0.111	0.99	1	1	0.08
0.111	1	1	1	0.08

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.49	7
2X	0	0	0.49	7
3X	0	0	0.49	7
4X	0	0	0.49	7
5X	0	0	0.49	7
6X	0	0	0.49	7
7X	0	0	0.49	7
8X	0	0	0.49	7
9X	0	0	0.49	7
10X	0	0	0.49	7

The Revised AHP Results of Inventory Management

Decision Variables	Original Rating I.C.	I.S.	B.C.	D.T.	T.R.	Weights
Inventory Cost	1	0.13	1	7	0.13	0.09
Inventory Space	8	1	8	8	0.13	0.31
Budget Constraint	1	0.13	1	8	1	0.17
Delivery Time	0.14	0.13	0.13	1	0.13	0.02
Turnover rate	8	8	1	8	1	0.41

		1X			Weights
1	0.125	0.364	1	0.125	0.05
8	1	2.91	8	1	0.39
2.74	0.34	1	2.74	0.34	0.13
1	0.125	0.364	1	0.125	0.05
8	1	2.91	8	1	0.39

		2X			Weights
1	0.125	0.382	1	0.125	0.05
8	1	3.06	8	1	0.39
2.61	0.326	1	2.61	0.326	0.13
1	0.125	0.382	1	0.125	0.05
8	1	3.06	8	1	0.39

		3X			Weights
1	0.124	0.267	1	0.125	0.05
8	1	2.13	8	1	0.37
3.74	0.46	1	3.74	0.46	0.17
1	0.124	0.267	1	0.125	0.05
8	0.99	2.13	8	1	0.37

		4X			Weights
1	0.124	0.124	0.99	0.125	0.04
8	1	1	8	1	0.31
8	1	1	8	1	0.31
1	0.125	0.125	1	0.125	0.04
8	0.99	1	8	1	0.31

		5X			Weights
1	0.124	0.125	1	0.125	0.04
8	1	1	8	1	0.31
7.9	0.99	1	8	1	0.31
0.99	0.125	0.125	1	0.125	0.04
8	0.99	1	8	1	0.31

		6X			Weights
1	0.125	0.132	1	0.125	0.04
8	1	1	8	1	0.31
7.53	0.94	1	8	1	0.31
1	0.125	0.125	1	0.125	0.04
8	1	1	8	1	0.31

		7X			Weights
1	0.125	0.2	1	0.125	0.04
8	1	1.62	8	1	0.34
4.91	0.61	1	8	1	0.26
1	0.125	0.125	1	0.125	0.04
8	1	1	8	1	0.31

		8X			Weights
1	0.125	0.273	1	0.125	0.05
8	1	2.18	8	1	0.37
3.65	0.45	1	8	1	0.23
1	0.125	0.125	1	0.125	0.04
8	1	1	8	1	0.31

		9X			Weights
1	0.125	0.352	1	0.125	0.05
8	1	2.82	8	1	0.38
2.83	0.35	1	8	1	0.22
1	0.125	0.125	1	0.125	0.04
8	1	1	8	1	0.31

		10X			Weights
1	0.125	0.45	1	0.125	0.05
8	1	3.64	8	1	0.40
2.19	0.274	1	8	1	0.20
1	0.125	0.125	1	0.125	0.04
8	1	1	8	1	0.31

	C.I.	C.R.	Average Change	Maximum Change
1X	0	0	0.98	7
2X	0	0	0.99	7
3X	0	0	1.00	7
4X	0	0	1.22	7
5X	0	0	1.21	7
6X	0	0	1.18	7
7X	0.01	0.01	0.96	7
8X	0.02	0.02	0.86	7
9X	0.04	0.04	0.79	7
10X	0.05	0.04	0.73	7

Appendix D

DEA Questionnaire

The Questionnaire Used for Research Only

เรื่อง การวิเคราะห์ประสิทธิภาพของโซ่อุปปานในเรื่องโลจิสติกส์ของอุตสาหกรรมไหมไทย

(Efficiency Analysis of the Supply Chains in the Thai Silk Industry)

<u>Statement of purpose</u>

The purpose of this questionnaire is to be used as a part of PhD research study to help the development logistic and supply chain model which supports policy decisions of the Thai government and the decision makers in the Thai silk field. The research concentrate mainly on Supply Chains. The results will be used to suggest improvements in the decision making process and configuration of the Thai silk's supply chain.

The aggregated results of the questionnaire will be used for data analysis in my Ph.D. thesis and scientific publications. However, no individual company will be identified by name.

Thank you for your cooperation

....

(Natawat Jatuphatwarodom)

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1.Shinawatra

Do you want suppliers to remain anonymous? □ Yes □ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5
Supplier-5	1	2	3	4	5

Service Level					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5
Supplier-5	1	2	3	4	5

Management					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5
Supplier-5	1	2	3	4	5

Financial Position					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5
Supplier-5	1	2	3	4	5

2. Kampo Thai silk

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Service Level					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Management					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Financial Position					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

3. Classic Model

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Service Level					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Management					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Financial Position					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

4. PNL

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Service Level					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Management					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Financial Position					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

5. Watchara Thai Silk

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Service Level					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Management					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

Financial Position					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5

6. Chattong Thai Silk

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Service Level					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Management					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Financial Position					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

7. Chalieo Thai Silk

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Service Level					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Management					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Financial Position					
	Very Bad	**Bad**	**Average**	**Good**	**Excellent**
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

8. Paothong Thai Silk

Do you want suppliers to remain anonymous? ☐ Yes ☐ No
Please indicate how you feel about these factors of your suppliers

Product Quality					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Service Level					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Management					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Financial Position					
	Very Bad	Bad	Average	Good	Excellent
Supplier-1	1	2	3	4	5
Supplier-2	1	2	3	4	5
Supplier-3	1	2	3	4	5
Supplier-4	1	2	3	4	5

Appendix E

LINGO Data for the DEA Analysis

Supplier Selection

1.Shinawatra

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  1300     8      5       4       3       3    4
        1400     10     7       4       3       3    2
        1050     8      8       4       3       2    4
        950      5      3       4       5       4    5
        1200     7      5       4       2       4    3;
 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

2. Kampo Thai silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  900     2      1       5       2       3    4
        700     2      1       3       4       4    3
        1200    3      2       4       4       3    4
        950     1      1       5       3       4    3;


 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

3. Classic Model

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  3200    4      3       5       4       5    4
        3500    5      3       5       4       3    4
        3000    2      2       5       5       5    5
        4000    5      3       4       5       4    4;
 ENDDATA
!-----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

4. PNL

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  850     2      2       5       3       3    4
        1000    3      3       4       4       5    4
        1200    3      3       4       4       4    4;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

5. Watchara Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  900     2      2       4       4       3    4
        1100    3      2       5       4       5    4
        1200    3      2       4       4       4    2;
 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

6. Chattong Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  850     2      1       5       3       3    4
        1000    3      2       4       4       5    4
        1050    5      3       4       3       2    4
        950     5      3       4       5       4    5;


 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

7. Chalieo Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  850     3      1       5       3       4    4
        1000    2      2       3       4       5    3
        1200    3      3       4       2       3    3
        1300    5      3       4       3       3    4;


 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

8. Paothong Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4/:
     SCORE;
  FACTOR/ Cost Labour Vehicle PQ SL M FF/;
! There is a set of factors, input & output;
  DXF(DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 3;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      Cost  Labour Vehicle     PQ      SL      M    FF;
  F  =  1200     7      4       4       3       2    3
        1300     4      2       5       4       3    4
        1100     4      3       5       4       3    4
        1300     8      4       4       3       3    2;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
MAX = @SUM( DMU: SCORE);

! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;

! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

Inventory Management

1.Shinawatra

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      SKUs  Space Labour  BC         IC      DT  TR;
  F  =  784   10    10     980000     10092   100   0.51
        392   5     7      490000     14796   100   0.71
        784   9     7      980000     10092   100   0.65
        784   10    7      980000     10092   100   0.77
        1176  15   15     1470000      5388   100   0.82;
 ENDDATA
!----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

2. Kampo Thai silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      SKUs  Space Labour  BC          IC      DT  TR;
  F  =  96    3    8       57600      848   100   0.73
        144   5    10      86400      605    80   0.64
        96    5     5      57600      848    80   0.78
        96    5     5      57600      848    90   0.64
        48    3     5      28800      424    80   0.66;
 ENDDATA
!-----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

3. Classic Model

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      SKUs  Space Labour  BC          IC       DT  TR;
  F  =  420   8    5       336000     11627   70   0.89
        560   8    10      448000     10780   80   0.78
        840   12   10      672000     8253    100  0.74
        420   8    5       336000     11627   90   0.80
        560   8    10      448000     10780   100  0.94;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

4. PNL

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5 DMU6 DMU7 DMU8 DMU9 DMU10/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      SKUs  Space Labour  BC          IC       DT  TR;
  F  =  450   5    10       750000   3267      90   0.80
        300   3    10      500000    3400      90  0.90
        450   5    10      750000    3267      80   0.87
        300   3    7      500000     3400      100  0.94
        150   3    5      250000     200       90   0.88

        300   3    7       500000     3400     90  0.94
        300   3    10       500000    3400     80   0.70
        150   3    5      250000      200      85   0.76
        150   3    5       250000     200      90  0.72
        450   5    7       750000     3267     100   0.92;
 ENDDATA
!-----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

5. Watchara Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5 DMU6 DMU7 DMU8 DMU9 DMU10/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                    the outputs;

!      SKUs  Space Labour  BC          IC       DT  TR;
  F  =  350   5    5       583333     3800   95   0.86
        175   3    5       291667     900    100  0.96
        350   5    5       583333     3800   80   0.94
        525   7    7       875000     3367   90   0.54
        350   3    5       583333     3800   100  0.69

        350   3    7       583333     3800   90  0.94
        175   3    5       291667     900    75  0.99
        525   7    7       875000     3367   90  0.86
        350   5    5       583333     3800   100  0.98
        350   5    5       583333     3800   100  0.77;
 ENDDATA
!-----------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

6. Chattong Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5 DMU6 DMU7 DMU8 DMU9 DMU10/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      SKUs  Space Labour  BC          IC       DT  TR;
  F  =  350   3    5       140000    1800      100   0.86
        350   3    5       140000    1800      90    1
        525   5    7       210000     367      100   0.95
        350   3    5       140000     1800     100   0.86
        175   3    5       70000      1900     80    0.71

        350   3    5       140000     1800     90    0.96
        525   5    7       210000     367      100   0.95
        175   3    5       70000      1900     100   0.79
        350   5    5       140000     1800     90    0.93
        350   5    5       140000     1800     100   0.86;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

7. Chalieo Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5 DMU6 DMU7 DMU8 DMU9 DMU10/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      SKUs  Space Labour  BC          IC      DT  TR;
  F  =  263   5    7      175000     1517   90   0.86
        175   3    5      116667     1900   100  0.77
        263   5    7      175000     1517   100   0.91
        175   3    7      116667     1900   100  0.77
        88    3    5      58333      950    90   0.94

        175   3    7       116667     1900   95  0.94
        175   3    5       116667     1900   80   0.69
        88    3    5       58333      950    100   0.94
        88    3    5       58333      950    90  0.82
        263   5    7       175000     1517   100   0.91;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

8. Paothong Thai Silk

```
MODEL:
! Data Envelope Analysis of Decision Maker Efficiency ;
 SETS:
  DMU/DMU1 DMU2 DMU3 DMU4 DMU5 DMU6 DMU7 DMU8 DMU9 DMU10/:
     SCORE;
  FACTOR/SKU IS LABOUR BC IC DT TURN/;
! There is a set of factors, input & output;
  DXF( DMU, FACTOR):  F; ! F( I, J) = Jth factor of DMU I;
 ENDSETS
 DATA:
 NINPUTS = 4;  ! The first NINPUTS factors are inputs;
!      The inputs,                     the outputs;

!      SKUs  Space Labour  BC          IC      DT  TR;
  F  =  280   5    8       354667      6640   90   0.85
        840   8    10      1064000     6587   100  0.77
        560   7    10      709333      8280   80   0.85
        560   7    10      709333      8280   100  0.90
        840   10   10      1064000     6587   80   0.75

        560   7    8       709333      8280   100  0.92
        560   7    8       709333      8280   85   0.78
        560   8    8       709333      8280   90   0.63
        560   7    8       709333      8280   100  0.73
        280   5    8       354667      6640   80   0.79;
 ENDDATA
!------------------------------------------------------------;
! The Model;
 SETS:
   ! Weights used to compute DMU I's score;
   DXFXD(DMU,FACTOR) : W;
 ENDSETS
! Try to make everyone's score as high as possible;
  MAX = @SUM( DMU: SCORE);
! The LP for each DMU to get its score;
  @FOR( DMU( I):
   SCORE( I) = @SUM( FACTOR(J)|J #GT# NINPUTS:
    F(I, J)* W(I, J));
! Sum of inputs(denominator) = 1;
   @SUM( FACTOR( J)| J #LE# NINPUTS:
    F( I, J)* W( I, J)) = 1;
! Using DMU I's weights, no DMU can score better than 1;
   @FOR( DMU( K):
    @SUM( FACTOR( J)| J #GT# NINPUTS: F( K, J) * W( I, J))
     <= @SUM( FACTOR( J)| J #LE# NINPUTS:
      F( K, J) * W( I, J))
   )
  );
! The weights must be greater than zero;
  @FOR( DXFXD( I, J): @BND( .00001, X, 100000));
END
```

Appendix F

DEA Results

DEA Inputs and Outputs for Supplier Selection Analysis.

Kampo Thai silk	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	900	2	1		5	2	3	4
Supplier-2	700	2	1		3	4	4	3
Supplier-3	1200	3	2		4	4	3	4
Supplier-4	850	1	1		5	3	4	3

PNL	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	850	2	2		5	3	3	4
Supplier-2	1000	3	3		4	4	5	4
Supplier-3	1200	3	3		4	4	4	4

Watchara	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	900	2	2		4	4	3	4
Supplier-2	1100	3	2		5	4	5	4
Supplier-3	1200	3	2		4	4	4	2

Chattong Thai Silk	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	850	2	1		5	3	3	4
Supplier-2	1000	3	2		4	4	5	4
Supplier-3	1050	5	3		4	3	2	4
Supplier-4	950	5	3		4	5	4	5

Chalieo Thai Silk	Inputs				Outputs			
Suppliers	Average Cost per Unit	Labours	Vehicles		Product Quality	Service Level	Management	Financial Flow
Supplier-1	850	3	1		5	3	4	4
Supplier-2	1000	2	2		3	4	5	3
Supplier-3	1200	3	3		4	2	3	3
Supplier-4	1300	5	3		4	3	3	4

DEA Inputs and Outputs for Inventory Management Analysis.

Kampo Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Mandarin neck-1	96	3	57600	8		848	100	0.73
Sample Order 2	Shawl neck-1	144	5	86400	10		605	80	0.64
Sample Order 3	Peter neck-1	96	5	57600	5		848	80	0.78
Sample Order 4	Boat neck-1	96	5	57600	5		848	90	0.64
Sample Order 5	Shirt neck-1	48	3	28800	5		424	80	0.66

PNL		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Dresses-1	450	5	750000	10		3267	90	0.80
Sample Order 2	Round neck-1	300	3	500000	10		3400	90	0.90
Sample Order 3	Boat neck-1	450	5	750000	10		3267	80	0.87
Sample Order 4	Dresses-2	300	3	500000	7		3400	100	0.94
Sample Order 5	Peter neck-1	150	3	250000	5		200	90	0.88
Sample Order 6	Boat neck-2	300	3	500000	7		3400	90	0.94
Sample Order 7	Dresses-3	300	3	500000	10		3400	80	0.70
Sample Order 8	Round neck-2	150	3	250000	5		200	85	0.76
Sample Order 9	Peter neck-2	150	3	250000	5		200	90	0.72
Sample Order 10	Dresses-4	450	5	750000	7		3267	100	0.92

Watchara Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Shirt neck-1	350	5	583333	5		3800	95	0.86
Sample Order 2	Dresses-1	175	3	291667	5		900	100	0.96
Sample Order 3	Round neck-1	350	5	583333	5		3800	80	0.94
Sample Order 4	Boat neck-1	525	7	875000	7		3367	90	0.54
Sample Order 5	Peter neck	350	3	583333	5		3800	100	0.69
Sample Order 6	Shawl neck	350	3	583333	7		3800	90	0.94
Sample Order 7	Dresses-2	175	3	291667	5		900	75	0.99
Sample Order 8	Shirt neck-2	525	7	875000	7		3367	90	0.86
Sample Order 9	Round neck-2	350	5	583333	5		3800	100	0.98
Sample Order 10	Boat neck-2	350	5	583333	5		3800	100	0.77

Chattong Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Boat neck-1	350	3	140000	5		1800	100	0.86
Sample Order 2	Shirt neck-1	350	3	140000	5		1800	90	1.00
Sample Order 3	Convertible neck-1	525	5	210000	7		367	100	0.95
Sample Order 4	Shawl neck-1	350	3	140000	5		1800	100	0.86
Sample Order 5	Peter neck	175	3	70000	5		1900	80	0.71
Sample Order 6	Shirt neck-2	350	3	140000	5		1800	90	0.96
Sample Order 7	Shawl neck-2	525	5	210000	7		367	100	0.95
Sample Order 8	Convertible neck-2	175	3	70000	5		1900	100	0.79
Sample Order 9	Boat neck-2	350	5	140000	5		1800	90	0.93
Sample Order 10	Shirt neck-3	350	5	140000	5		1800	100	0.86

Chalieo Thai Silk		Inputs					Outputs		
	Style	SKUs	Inventory Space	Budget	Labours		Inventory Cost	Delivery Time	Turnover Rate
Sample Order 1	Boat neck-1	263	5	175000	7		1517	90	0.86
Sample Order 2	Round neck-1	175	3	116667	5		1900	100	0.77
Sample Order 3	Convertible neck-1	263	5	175000	7		1517	100	0.91
Sample Order 4	Peter neck-1	175	3	116667	7		1900	100	0.77
Sample Order 5	Shawl neck	88	3	58333	5		950	90	0.94
Sample Order 6	Mandarin neck	175	3	116667	7		1900	95	0.94
Sample Order 7	Convertible neck-2	175	3	116667	5		1900	80	0.69
Sample Order 8	Round neck-2	88	3	58333	5		950	100	0.94
Sample Order 9	Boat neck-2	88	3	58333	5		950	90	0.82
Sample Order 10	Peter neck-2	263	5	175000	7		1517	100	0.91

DEA Scores

Suppliers' Efficiency Analysis			Inventories' Efficiency Analysis	
	Suppliers	DEA Scores	Sample Orders	DEA Scores
Kampo Thai Silk	Supplier-1	1	Mandarin neck-1	1
	Supplier-2	1	Shawl neck-1	0.58
	Supplier-3	0.78	Peter neck-1	1
	Supplier-4	1	Boat neck-1	1
			Shirt neck-1	1
PNL	Supplier-1	1	Dresses-1	0.67
	Supplier-2	1	Round neck-1	1
	Supplier-3	0.91	Boat neck-1	0.67
			Dresses-2	1
			Peter neck-1	1
			Boat neck-2	1
			Dresses-3	1
			Round neck-2	0.94
			Peter neck-2	1
			Dresses-4	0.99
Watchara Thai Silk	Supplier-1	1	Shirt neck-1	1
	Supplier-2	1	Dresses-1	1
	Supplier-3	1	Round neck-1	1
			Boat neck-1	0.64
			Peter neck	1
			Shawl neck	1
			Dresses-2	1
			Shirt neck-2	0.64
			Round neck-2	1
			Boat neck-2	1
Chattong Thai Silk	Supplier-1	1	Boat neck-1	1
	Supplier-2	1	Shirt neck-1	1
	Supplier-3	0.8	Convertible neck-1	0.74
	Supplier-4	0.65	Shawl neck-1	1
			Peter neck	1
			Shirt neck-2	0.99
			Shawl neck-2	0.74
			Convertible neck-2	1
			Boat neck-2	0.98
			Shirt neck-3	1
Chalieo Thai Silk	Supplier-1	1	Boat neck-1	0.72
	Supplier-2	1	Round neck-1	1
	Supplier-3	0.8	Convertible neck-1	0.76
	Supplier-4	0.65	Peter neck-1	1
			Shawl neck	1
			Mandarin neck	1
			Convertible neck-2	1
			Round neck-2	1
			Boat neck-2	1
			Peter neck-2	0.76

Appendix G

GP Questionnaire

The Questionnaire Used for Research Only

เรื่อง การวิเคราะห์ประสิทธิภาพของโซ่อุปทานในเรื่องโลจิสติกส์ของอุตสาหกรรมไหมไทย

(Finding of Optimal Solutions using Goal-Programing)

<u>Statement of purpose</u>

The purpose of this questionnaire is to be used as a part of PhD research study to help the development logistic and supply chain model which supports policy decisions of the Thai government and the decision makers in the Thai silk field. The research concentrate mainly on Supply Chains. The results will be used to suggest improvements in the decision making process and configuration of the Thai silk's supply chain.

The aggregated results of the questionnaire will be used for data analysis in my Ph.D. thesis and scientific publications. However, no individual company will be identified by name.

Thank you for your cooperation

....

(Natawat Jatuphatwarodom)

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A: Please rate the difficulty levels of affords that you feel to implement these actions

Actions	Difficulty Levels				
	Easy	Normal	Hard	Very Hard	Intense
Work with suppliers to improve communications in the supply chain.					
Negotiate lower lead times with suppliers.					
Reduce the number of part numbers carried.					
Take credit and track your efforts to reduce inventory.					
Find ways to reduce surplus and obsolete inventory.					
Improve supplier's quality to reduce costs.					
Challenge and reduce minimum order quantities.					
Improve suppliers on time delivery performance.					
Set up a supplier managed inventory programs.					

Easy=1, Normal=2, Hard=4, Very Hard=7, Intense=10

B: Please rate the percentage changes if those actions are utilize.

Actions	Goals				
	minimise inventory cost for one order (TH Baht)	minimise space used for one order in inventory (squre	minimise budget for one order in inventory (TH Baht)	maximise delivery Time rate (Percentage)	maximise turnover ratio (Up to 1)
	Avg value. XXX	Avg value XXX	Avg value XXX	Avg value. XXX	Avg value. XXX
	Target	Target	Target	Target	Target
	Percentage Change	Percentage Change	Percentage Change	Percentage Change	Percentage Change
Work with suppliers to improve communications in the supply chain.					
Negotiate lower lead times with suppliers.					
Reduce the number of part numbers carried.					
Take credit and track your efforts to reduce inventory.					
Find ways to reduce surplus and obsolete inventory.					
Improve supplier's quality to reduce costs.					
Challenge and reduce minimum order quantities.					
Improve suppliers on time delivery performance.					
Set up a supplier managed inventory programs.					
45 sets of contributions in Total.					

Appendix H

GP Results

GP Data Collection

Kampo Thai Silk		Difficulty Levels				
Actions		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.		■			
X2	Negotiate lower lead times with suppliers.				■	
X3	Reduce the number of part numbers carried.			■		
X4	Take credit and track your efforts to reduce inventory.			■		
X5	Find ways to reduce surplus and obsolete inventory.		■			
X6	Improve supplier's quality to reduce costs.					■
X7	Challenge and reduce minimum order quantities.			■		
X8	Improve suppliers on time delivery performance.			■		
X9	Set up a supplier managed inventory programs.					■
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

PNL		Difficulty Levels				
Actions		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.	■				
X2	Negotiate lower lead times with suppliers.			■		
X3	Reduce the number of part numbers carried.				■	
X4	Take credit and track your efforts to reduce inventory.		■			
X5	Find ways to reduce surplus and obsolete inventory.			■		
X6	Improve supplier's quality to reduce costs.				■	
X7	Challenge and reduce minimum order quantities.				■	
X8	Improve suppliers on time delivery performance.					■
X9	Set up a supplier managed inventory programs.				■	
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Watchara Thai Silk		Difficulty Levels				
Actions		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.			■		
X2	Negotiate lower lead times with suppliers.				■	
X3	Reduce the number of part numbers carried.		■			
X4	Take credit and track your efforts to reduce inventory.	■				
X5	Find ways to reduce surplus and obsolete inventory.			■		
X6	Improve supplier's quality to reduce costs.					■
X7	Challenge and reduce minimum order quantities.				■	
X8	Improve suppliers on time delivery performance.				■	
X9	Set up a supplier managed inventory programs.					■
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Chattong Thai Silk		Difficulty Levels				
Actions		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.	■				
X2	Negotiate lower lead times with suppliers.				■	
X3	Reduce the number of part numbers carried.			■		
X4	Take credit and track your efforts to reduce inventory.	■				
X5	Find ways to reduce surplus and obsolete inventory.	■				
X6	Improve supplier's quality to reduce costs.				■	
X7	Challenge and reduce minimum order quantities.				■	
X8	Improve suppliers on time delivery performance.				■	
X9	Set up a supplier managed inventory programs.					■
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Chalieo Thai Silk		Difficulty Levels				
Actions		Easy	Normal	Hard	Very Hard	Intense
X1	Work with suppliers to improve communications in the supply chain.		■			
X2	Negotiate lower lead times with suppliers.				■	
X3	Reduce the number of part numbers carried.		■			
X4	Take credit and track your efforts to reduce inventory.	■				
X5	Find ways to reduce surplus and obsolete inventory.		■			
X6	Improve supplier's quality to reduce costs.				■	
X7	Challenge and reduce minimum order quantities.				■	
X8	Improve suppliers on time delivery performance.					■
X9	Set up a supplier managed inventory programs.				■	
Remark: Easy = 1, Normal = 2, Hard = 5, Very Hard = 8, Intense = 10						

Contribution Sets for GP Data Analysis

	Goals									
Kampo Thai Silk	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
Actions	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	2285	1800	4.2	3	600	400	86	100	0.69	1
Work with suppliers to improve communications in the supply chain.	229		0.4		60		17.2		0.138	
Negotiate lower lead times with suppliers.	1143		0.4		240		25.8		0.0345	
Reduce the number of part numbers carried.	686		1.3		120		17.2		0.138	
Take credit and track your efforts to reduce inventory.	686		0.8		60		17.2		0.0345	
Find ways to reduce surplus and obsolete inventory.	229		0.4		120		17.2		0.0345	
Improve supplier's quality to reduce costs.	686		1.3		120		8.6		0.069	
Challenge and reduce minimum order quantities.	114		0.2		60		8.6		0.138	
Improve suppliers on time delivery performance.	229		1.3		60		25.8		0.138	
Set up a supplier managed inventory programs.;	686		1.9		60		17.2		0.207	

	Goals									
PNL	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
Actions	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	9600	8000	3.6	2	1667	1200	90	100	0.84	1
Work with suppliers to improve communications in the supply chain.	960		0.4		167		36		0.168	
Negotiate lower lead times with suppliers.	2880		1.8		167		45		0.042	
Reduce the number of part numbers carried.	2880		1.1		833		9		0.042	
Take credit and track your efforts to reduce inventory.	1440		0.4		167		18		0.252	
Find ways to reduce surplus and obsolete inventory.	1920		1.4		333		27		0.084	
Improve supplier's quality to reduce costs.	4320		1.1		667		9		0.084	
Challenge and reduce minimum order quantities.	480		0.2		167		9		0.168	
Improve suppliers on time delivery performance.	4800		1.1		333		27		0.168	
Set up a supplier managed inventory programs.;	2880		0.4		667		36		0.588	

	Goals									
Watchara Thai Silk	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
Actions	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	9867	8000	4.6	3	1667	1200	92	100	0.85	1
Work with suppliers to improve communications in the supply chain.	987		0.5		167		36.8		0.17	
Negotiate lower lead times with suppliers.	2960		0.9		167		27.6		0.0425	
Reduce the number of part numbers carried.	2960		1.4		333		18.4		0.0425	
Take credit and track your efforts to reduce inventory.	1480		0.9		167		18.4		0.0425	
Find ways to reduce surplus and obsolete inventory.	987		1.8		333		18.4		0.0425	
Improve supplier's quality to reduce costs.	4440		1.4		667		9.2		0.085	
Challenge and reduce minimum order quantities.	493		0.2		167		9.2		0.17	
Improve suppliers on time delivery performance.	2960		1.4		167		27.6		0.17	
Set up a supplier managed inventory programs.;	2960		2.1		667		36.8		0.595	

Chattong Thai Silk	Goals									
	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
Actions	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	6467	5000	3.8	2	400	300	95	100	0.89	1
Work with suppliers to improve communications in the supply chain.	647		0.4		40		38		0.18	
Negotiate lower lead times with suppliers.	1940		1.9		40		48		0.04	
Reduce the number of part numbers carried.	1940		1.1		200		10		0.04	
Take credit and track your efforts to reduce inventory.	970		0.4		40		19		0.27	
Find ways to reduce surplus and obsolete inventory.	1293		1.5		80		29		0.09	
Improve supplier's quality to reduce costs.	2910		1.1		160		10		0.09	
Challenge and reduce minimum order quantities.	323		0.2		40		10		0.18	
Improve suppliers on time delivery performance.	3234		1.1		80		29		0.18	
Set up a supplier managed inventory programs.;	1940		0.4		160		38		0.62	

Chalieo Thai Silk	Goals									
	minimise inventory cost for one order (TH Baht)		minimise space used for one order in inventory (squre metre)		minimise budget for one order in inventory (TH Baht)		maximise delivery Time rate (Percentage)		maximise turnover ratio (Up to 1)	
Actions	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target	Avg.	Target
	4500	3000	3.6	2	667	400	94.5	100	0.86	1
Work with suppliers to improve communications in the supply chain.	450		0.4		67		19		0.09	
Negotiate lower lead times with suppliers.	1125		1.1		67		28		0.09	
Reduce the number of part numbers carried.	1350		1.4		200		19		0.09	
Take credit and track your efforts to reduce inventory.	900		1.1		67		5		0.26	
Find ways to reduce surplus and obsolete inventory.	450		1.4		167		5		0.34	
Improve supplier's quality to reduce costs.	1350		1.4		267		9		0.09	
Challenge and reduce minimum order quantities.	225		0.2		133		5		0.17	
Improve suppliers on time delivery performance.	1125		1.1		133		19		0.17	
Set up a supplier managed inventory programs.;	1800		1.1		334		28		0.34	

A Summary of GP Analysis